APPENDIX F

METHOW BASIN (WRIA 48) STORAGE ASSESSMENT

METHOW BASIN (WRIA 48)

STORAGE ASSESSMENT

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

APPENDICES

1.0 INTRODUCTION

1.1 Purpose of the Assessment

The purpose of the storage assessment is to determine the feasibility of storing water during periods of “excess” capacity, for use during periods of limited capacity. It includes:

- A general overview of potential storage options, including off-channel storage, underground storage, enlargement or enhancement of existing storage and on channel storage;
- An inventory of existing storage facilities, available infrastructure, and storage volumes;
- A discussion of issues associated with developing storage, including potential environmental effects; and
- A summary of storage modeling conducted by the US Bureau of Reclamation (USBR).

1.2 Basic Concepts of Storage

The basic concept of storage is to collect water when there is excess, hold it with a minimum amount of loss or leakage, and use it during periods of limited supply or high demand. By convention, storage project are typically developed in volumetric units, acre feet (AF), or million gallons (MG). Units of AF are used in this report. One AF of water is equivalent to 0.33 MG of water.

Water storage could be used for several purposes:

1. To offset current demands on existing systems;
2. To offset future demands on existing systems;
3. To apply to new water uses in new or expanded systems; and
4. To enhance streamflows.

Enhancement of streamflows or prevention of further impacts to streamflows is typically a resultant benefit of managing storage for existing or future uses. Although there are physical constraints on potential storage locations, priorities addressing what water storage should be used for also influence the selection of potential storage locations. Priority uses of storage could include:

- Storage projects that can be integrated with the operation of existing systems and can also be used to supplement streamflows in critical habitat areas. This would apply to current and future demands of existing systems;
- Storage projects that can enhance streamflows in critical habitat areas, but do not provide a benefit to existing or new systems; and
- Storage projects that can be integrated with the operation of new or existing systems, without benefit to streamflows.

1.3 Water Storage Task Force

The water storage task force was convened by Washington Department of Ecology (WDOE) in 2000 to examine the role of water storage in managing the state’s water resources. The report to the legislature provides a variety of valuable information on storage and is included as Appendix A.

During the legislative session, the definition of a storage “reservoir” was expanded to include underground formations. This led to the development of permitting for Aquifer Storage and

Recovery or "ASR" projects. A 2001 report to the legislature provides a variety of information on ASR and is provided in Appendix B.

1.4 Water Storage SEPA Elements Related to RCW 90.82

WDOE has addressed six potential water storage alternatives in its programmatic EIS for watershed planning, as described below.

Alternative WP 19: Construct and operate new on-channel storage facilities. Under this alternative, a water storage facility would be created by impounding a river or stream. On-channel storage facilities could include large reservoirs on the mainstem of major rivers as well as small reservoirs on tributary streams. Construction could involve creation of an earthen dam or a concrete dam.

Alternative WP 20: Raise and operate existing on-channel storage facilities. Under this alternative the capacity of an existing on-channel reservoir would be increased by raising or enlarging the impoundment structure.

Alternative WP 21: Construct and operate new off-channel storage facilities. Under this alternative, an impoundment structure, either earthen or concrete, would be created in an upland location. Water would be diverted, or more likely pumped, from a river to an off-channel location for storage. Off-channel facilities could have a wide range of capacities.

Alternative WP 22: Raise and operate existing off-channel storage facilities. Under this alternative the capacity of an existing off-channel reservoir would be increased by raising or enlarging the impoundment structure.

Alternative WP 23: Use existing storage facilities for additional beneficial uses. Operation of a storage facility constructed to provide water for one specific beneficial use or group of uses could be modified to provide water for additional beneficial uses. For example, use of a storage facility originally constructed for municipal water supply could be expanded to supply water for irrigation or to provide additional flows for fish during critical life stages.

Alternative WP 24: Construct and operate artificial recharge/aquifer storage. Aquifer storage and recovery involves introducing water, usually surface water from rivers, into an aquifer through injection wells or through surface spreading and infiltration. The introduced water is stored in the aquifer until needed and then withdrawn from the aquifer through wells for beneficial use. Water to be stored in an aquifer must meet the state's ground water quality standards, Chapter 173-200 WAC. Aquifer storage and recovery does not include operational losses of water during irrigation of land; water artificially stored due to construction, operation, or maintenance of an irrigation system; or to projects involving recharge of reclaimed water (RCW 90.03.370).

1.5 Current Conditions

Water demand, existing storage and consumptive use in WRIA 48 was evaluated in the Phase II technical assessment (Golder, 2002). Estimates of current storage in the basin are summarized from two sources:

- Water Resources Management Program (Kauffman and Bucknell, 1976); and
- Hydrographic Data - Dams (Ecology, 2001).

Existing reservoirs are summarized in Table 1-1. Existing dams and their respective storage volumes are summarized in Table 1-2. Dams information from Ecology identifies 18 dams with a total storage available of 6,071 AF. The majority of these dams are designated for recreation purposes. The location of existing dams is shown on Figure 1-1.

Two screening level water storage studies have been conducted which focus on potential storage in the Methow Basin:

- The Methow River Basin Level B Study (Washington State Study Team, 1977) identified the potential for about 23,500 acre-feet of additional storage in the Basin. Dam heights used in the estimates ranged from 15 to 55 feet, with yields of individual storage projects ranging from 200 to 17,000 acre-feet. The reported storage potential was greatest in the Chewuch Basin (8,000 AF), followed by the Lower Methow (7,365 AF), Twisp (5,900 AF) and Middle Methow (2,250 AF). An additional 17 sites were identified in the report but documentation on the analysis was poor.

- The Methow Valley Water Planning Pilot Project also evaluated storage in the basin (Klohn Leonoff, 1993). This study identified 24 potential reservoir sites. These sites are described in Table 1-3. Possible dam sites were identified based on stream habitat, capacity, capacity/run-off ratio, and dam crest length to reservoir capacity ratio. Dam heights of 40 feet and 80 feet were used in the analysis, and capacity ranged from less than 50 to 700 AF for 40-foot dams and from about 150 to 2,600 AF for 80-foot dams. The reported total storage capacity from the 24 potential sites using 40-foot was only 5,042 AF. Using 80-foot structures, 25,548 AF of total capacity is reported. Patterson Lake was identified as the first choice for additional storage.

Both studies recognize that there is plenty of water available in the basin on an annualized basis, and that the value of storage is to store excess spring runoff for use in the summer low flow period, and possibly for use in drought years when even the spring runoff is inadequate (Klohn Leonoff, 1993). Groundwater storage has previously been dismissed as an option due to the assumption of a short lag time for groundwater return to the surface (Klohn Leonoff, 1993).

2.0 OVERVIEW SURFACE WATER STORAGE ALTERNATIVES

This section provides an overview of surface water storage alternatives for WRIA 48.

2.1 Types of Surface Water Storage

2.1.1 Reservoirs Dams and Impoundments

There are two types of reservoirs: on-channel and off-channel reservoirs. On-channel reservoirs are situated on the main stem of a river or stream and are filled by the flow from the upstream watershed. Off-channel reservoirs are located on a small tributary or completely off the river. These reservoirs are filled by overland flow from the natural basin and by gravity or pumped flow from a nearby basin.

Each of these reservoirs has benefits and drawbacks. For an on-channel reservoir, benefits may include flood control and the storage of large amounts of water. Drawbacks include being a barrier to fish passage, relocation of people and infrastructure when the reservoir is created and the need for flood flow spillways and outlet works. For an off-channel reservoir, benefits may include not being located in an environmentally sensitive area, not being a barrier to fish passage and needing smaller spillways and outlet works. Drawbacks include construction of infrastructure to convey water to and from the reservoir, higher construction and operations and maintenance costs, and reservoir leakage and seepage.

For any reservoir to be successful, it must be located at a site that allows for the construction of a safe dam, have a catchment (or water source) large enough to reliably refill the reservoir, and provide enough water to be beneficial. Choosing a site can be difficult.

The recently enacted State Senate Bill 5575 exempts small irrigation facilities from the requirement to obtain a reservoir permit for small irrigation impoundments of less than 10 acre-feet. The impoundment must be filled with water that is obtained under an existing, valid water right, and must not expand the number of irrigated acres attributed to that right. Development and use of the water from the impoundment does not require a water right holder to change, transfer or amend any existing water right.

Appendix A contains a variety of useful information and terminology related to dams and impoundments.

2.2 Availability of “Excess” Surface Water for Storage

In WRIA-48, a significant issue is the availability of “excess” water to use as storage. The Methow River and its major tributaries are subject to instream flow requirements. However, flows over the instream flow requirements are “excess” and could be withdrawn from the river for any beneficial uses, including storage. Table 2-1 summarizes regulatory baseflows for the Methow Basin. Table 2-2 shows the average difference between daily streamflow and regulator baseflows. Table 2-3 shows the average annual volume of streamflow in excess of regulatory baseflows. Table 2-4 shows the average number of days when streamflow exceeded regulatory baseflows. Table 2-5 shows the annual volume of excess flows on days when flows exceeded baseflows. These tables show that there are days in every year when streamflow exceeds regulatory baseflow and that the volumes are typically significant (9,000 to over 1 million AF). During the 2001 drought excess streamflow was limited.

2.3 Technical Requirements

2.3.1 General

Typical study needs for a surface water reservoir include:

- Geotechnical site investigation: Includes geotechnical test pits or subsurface borings evaluating geology around outlet structure area of lake. Determination of subsurface conditions for foundation of dike structures, subsurface seepage issues, evaluation of requirement of cut-off walls, etc.
- Site Survey and Land Use analysis: Option includes either land survey or aerial survey of lake perimeter and dam structure area of development of engineering grade topographic data. Data is used for evaluation of land impacts due to increased water surface elevations, and design of dam structure. Ownership issues are also addressed here.
- Hydrological study: includes assessment of inflow/outflow magnitudes, flood flow analysis, operational rule curves, and carry-over storage.
- Engineering design of the dam: Includes all aspects of analysis/evaluation of dam and corresponding wing dikes for raising water levels, as well as subsurface cut-off wall requirements addressing subsurface seepage.
- Securing of Water Rights: To be secured prior to dam design permit application.
- Permitting of Dam Structure: Highly variable, dependent on regulatory setting.
- Construction or Modification of Dam: Geotechnical and design phase will determine final construction requirements

2.3.2 Treatment and Conveyance Requirements

Surface water storage for potable supply requires a full treatment plant to meet safe drinking water standards. Storage for agricultural supply or streamflow mitigation does not typically require such stringent water quality requirements.

2.3.3 Permitting/Legal Constraints

Construction of new surface water storage would most likely be off-stream and would involve multiple federal and state agency approvals. Expansion of existing facilities such as Patterson Lake or Pearrygin Lake, would also require additional permitting. Such a process could take several years before initiation of construction.

2.3.4 Financial Constraints

Comparative cost data for new dam and reservoir projects was assembled for the Water Storage Task Force in 2001. Storage projects ranging from 80 to 800,000 AF were evaluated. Costs for these projects ranged from $200/AF to $5,300/AF.

Costs for conveyance systems vary, and additional engineering analysis is needed to prepare more detailed cost estimates. In general, conveyance costs for a pipeline capable of peak flows of 30 mgd may be on the order of $2.5 million per mile. Operating costs are typically estimated at 0.5% of the capital cost.

2.3.5 Environmental Political/Regulatory Constraints

Dams or reservoirs have a long history of both real and perceived negative environmental impacts. New dams or expansion of existing dam facilities will introduce additional political complexities with the general public, affected stakeholders and local governments, creating both opportunities and challenges. Dams and reservoirs require an extensive public outreach effort, and need to be developed in an open and cooperative environment. Land use and the inherent environmental impacts of constructing a dam can often overwhelm the technical feasibility or benefit of a new or expanded reservoir. However, dams and reservoirs have a proven history in the water supply field, and could play an important role in storing water for both human and ecological needs.

3.0 OVERVIEW OF GROUND WATER STORAGE ALTERNATIVES

3.1 Types of Groundwater Storage

Groundwater storage can be a difficult concept, from both a technical and regulatory standpoint. Below the ground surface, water storage is difficult to visualize and measure in ways similar to a surface reservoir or impoundment. However, the seasonal rise and fall of water levels in aquifers is fundamentally a response to an increase or decrease in the amount of water stored in the aquifer. Aquifers are commonly described as reservoirs and in terms of the water that "flows" through them. Water that is stored naturally in an aquifer interacts closely with the water that flows through the aquifer, but the storage and flow components of groundwater flow are fundamentally different. Storage is an intrinsic property of the aquifer, while the rate and direction of water that flows through the aquifer is dependent on many other factors relating to the aquifer's boundary conditions. The maximum or minimum amount of storage in an aquifer can vary from year to year in response to climate. Over a long period, the amount of storage in an aquifer is actually negligible, since water molecules that were "stored" at one time eventually "flow" through the system to the discharge areas of the aquifer. Groundwater storage, therefore, is also time dependent.

The amount of storage in an aquifer can be artificially increased or decreased by manipulating recharge. Artificial recharge, or aquifer storage and recovery (ASR) projects are an increasingly popular approach to using underground aquifers as storage reservoirs. This introduces additional complexity because of the "co-mingling" of natural and artificial recharge. "Ownership" of water recharged artificially can become a difficult regulatory concept. Finally, like any storage project, it is necessary to have access to "excess" water to use for aquifer storage. This water has to be both legally available and economically accessible in order for a groundwater storage project to be feasible.

3.2 Aquifer Storage and Recovery (ASR)

Aquifer Storage and Recovery, or ASR, is a water resource management technique in which water is introduced into permeable geological formations using wells or infiltration basins, stored for a period of weeks or months, and then recovered for potable or other uses. ASR is being used throughout the world with facilities operating in many different environments, including Florida, California, New Jersey, Nevada, Utah, Texas, Arizona, and New Mexico. There are two fully operational ASR systems in the Pacific Northwest: the Highline Wellfield for Seattle Public Utilities and the Salem Heights wellfield for the City of Salem, Oregon. A number of promising feasibility and pilot projects are also underway throughout the Pacific Northwest, including Yakima and Walla Walla.

Technical water supply issues for ASR include:

- Suitable Receiving Aquifer: The receiving aquifer needs to have one of the following attributes: 1.) Physical or hydrochemical boundaries that restrict movement of the injected water and minimize water quality changes during storage; or 2.) Suitable discharge boundaries that provide mitigation to surface waters during ASR operations, if one purpose of ASR is to provide streamflow mitigation
- Suitable Source Water: Currently, water injected directly into aquifers for ASR purposes must meet drinking water quality standards. Injection of reclaimed water is not currently allowed in Washington. Infiltration of water into aquifers …..
- Acceptable Water Quality: ASR typically involves the mixing of waters from different sources. This can have positive or negative effects depending on site specific conditions.

- Adequate Infrastructure: Adequate transmission capacity between the source water and the receiving aquifer is essential. Since the location of a receiving aquifer is fixed, issues related to bringing adequate infrastructure to promising receiving aquifers could be significant.
- Suitable Demand Profile: ASR is, by nature, a non-continuous use. ASR systems are typically evaluated in terms of the total storage capacity, peak recovery capacity, and efficiency of recovery, rather than average annual yield. Seasonal or peaking supply is the typical use of ASR, whereby storage occurs during low demand periods (e.g. winter/spring) and water is recovered during high demand periods (e.g. summer/fall).

3.2.1 Environmental Impacts/Benefits

The environmental impacts or benefits from ASR will depend on the site specific conditions of the ASR system. Environmental impacts from an operating ASR system are generally minor, but could include:

- Water quality changes to the aquifer and associated beneficial uses;
- Slope stability under certain circumstances
- Detrimental increases or declines in aquifer levels;
- Detrimental increases or declines in surface discharges;

Significant environmental benefits of ASR may include:

Seasonal shifts in sources of water supply from direct surface or groundwater withdrawal to ASR during critical low flow periods can result in improved streamflow conditions.

Water quality improvement can be achieved through injection of high quality water into lower quality marginal aquifers.

Direct enhancement of river flows can occur by pumping an aquifer that has been artificially recharged. This could address concerns and mandates for the recovery of salmon species under the Endangered Species Act. The restoration of the Everglades in Florida is the most ambitious example of the use of ASR for environmental restoration, and has direct corollaries to conditions in the Pacific Northwest.

Indirect enhancement of river flows can occur through leakage from ASR systems to adjacent surface waters. Similar to the current concept of hydraulic continuity for groundwater withdrawals, groundwater injection works “in-reverse” and can improve baseflows to streams.

3.2.2 Permitting/Legal Constraints

ASR is permitted under WAC 173-157-040, which is provided in Appendix B. Three permits are necessary:

- A primary water right for the water that will be used for injection/recharge
- A permit to store the water
- A secondary permit to withdraw the stored water and put it to beneficial use (this permit is not always necessary, depending on the nature of the primary water right).

ASR projects have typically been used for municipal supply projects. Applications for irrigation or for direction augmentation of streams use are less common, probably because of the costs involved.

3.2.3 Financial Constraints

A systematic assessment of costs for ASR systems has not been published, and the estimates presented below are based on limited research of ASR systems nationwide. Feasibility and pilot testing programs generally range between $100,000 and $500,000 for systems with existing infrastructure.

Published annualized unit costs for developed water using ASR range from $30 to $350 per acre-foot ($92 to $920 per million gallons) for systems that do not require new treatment facilities. Costs are significantly higher for systems that require new treatment facilities or other major infrastructure upgrades.

3.2.4 Political/Regulatory Constraints

Large scale implementation ASR could introduce additional political complexities amongst stakeholders and local governments, creating both opportunities and challenges for cooperation. Aquifers do not coincide with jurisdictional boundaries and both impacts and benefits from ASR would need to be addressed in a cooperative environment. "Ownership" of water that is injected into an aquifer and that subsequently moves through the aquifer is a difficult issue to administer. However, ASR could play an important role in moving water where and when it is needed for both human and ecological needs.

3.3 Artificial Recharge and Indirect Streamflow Augmentation

Artificial recharge of shallow aquifers in hydraulic continuity with streams has been suggested as both a mitigation approach for new water rights and an environmental benefit to aquatic habitats. The feasibility of using this recharge/storage strategy is dependent on many site specific factors including:

- **Hydraulic continuity** between the aquifer and adjacent surface waters must be well characterized and understood. A detailed understanding is necessary to support estimation of the timing, magnitude, and location of streamflow benefits associated with artificial recharge. This typically requires a combination of well installation, aquifer testing, groundwater level monitoring and modeling analysis. Typically, characterization cannot resolve all uncertainties in the hydrogeologic understanding, and impact analyses need to consider the range of hydrologic impact associated with the range of uncertainty. The USGS study on the Twisp River (Konrad, 2003) is an example of the type of information needed.
- **Streamflow hydrographs** and variability are important factors in order to understand how well artificial recharge and natural groundwater storage can offset low flows during the fall/winter. This aspect is important from both a physical and a regulatory standpoint.
- **Return flow** is an important factor to evaluate how recharge moves from the recharge source and how it discharges to a stream. Modeling analyses are required to estimate the timing and magnitude of return flow to the stream or river. Water rights may be necessary for water that is infiltrated for mitigation. The PCHB digest (Mentor Law Group, 2001) indicates that mitigation credits are not issued for the incidental infiltration of captured stormwater runoff. However, if a water right is obtained for the capture and beneficial use, it can be used for flow augmentation and associated mitigation.

3.4 USGS Groundwater Study

The USGS conducted a study that evaluated the feasibility of artificial recharge at six locations in the Methow Basin. This report is provided in its entirety in Appendix D.

4.0 USBR RIVERWARE MODELING

The US Bureau of Reclamation (USBR) used the river and reservoir management model RiverWare to compare the seven alternatives, by using daily inflows created by the US Geologic Survey (USGS) Precipitation-Runoff Model for the Methow Basin.

4.1 Description of RiverWare

RiverWare is a generalized river basin modeling tool which integrates the purposes of reservoir systems, such as flood control, navigation, recreation and water supply. RiverWare provides a tool for scheduling, forecasting and planning reservoir operations

RiverWare uses an object-oriented modeling and software approach which is "data-centered", in that a specific river/reservoir system and its operating policies are defined by the data supplied to the model. This allows a basin model to be modified to reflect new features or new operating policies, and allows transportability to other river basins. RiverWare is currently being used by the USBR at a number of locations throughout the US.

4.2 Description of Methow Basin RiverWare Analysis

The network for the Methow River Basin was developed based on discussions with the Methow Basin Planning Unit. Figure 4-1 shows the RiverWare model network developed for this analysis. The rivers simulated include Chewuch River, Methow River, Twisp River, and Wolf Creek. The RiverWare model uses simulated streamflows form the USGS hydrologic model (Ely and Risley, 2001). Boundary inflows are specified for the Methow River above the confluence with Wolf Creek, Chewuch River below the confluence with Falls Creek, Wolf Creek, Little Wolf Creek, Rader Creek, and Twisp River below the confluence with Buttermilk Creek. The boundary inflow data set is input on a daily timestep for the water years 1959 to 2001.

Storage conditions considered in the analysis were as follows:

- Existing Patterson Lake (3,330 AF)
- Existing Pearrygin Lake (1,000 AF)
- Enlarged Patterson Lake (+1,500 AF)
- Enlarged Pearrygin Lake (+638 AF)
- Uphill Reservoir (160 AF)
- Elbow Coulee Reservoir (1,275 AF)
- Deadhorse Reservoir (1,680 AF)
- All reservoirs were allowed annual carryover storage

Operations constraints considered in the analysis were as follows:

- Wolf Creek Reclamations District ESA Target Flows (NMFS BiOp, 2003)
- Skyline Irrigation Company ESA Target Flows (Pending BiOp, Johnson personal communication)
- State Baseflows (WAC 173-548)
- Table 4-1 Summarized the Modeled ESA Target Flows

Priorities for storage considered in the analysis were as follows:

- Release storage directly to river to meet target flows. In this case, storage is used first to meet target/baseflows
- Release storage directly to canals to meet irrigation delivery targets. In this case, storage is used first to meet irrigation deliveries

Seven storage scenarios were developed by the Methow Basin Planning Unit to evaluate proposed reservoir storage added to the Methow Basin. The seven scenarios were grouped as follows:

Alternative 1: Present Conditions (4,330 AF of Storage)

Alternative 2: Increase storage capacity by 5,335 AF using Pearrygin Lake, Patterson Lake, Elbow Coulee, and Deadhorse Reservoir. Operational scenarios and priorities under this alternative were as follows:

2A – Release storage with ESA target flow priority
2B – Release storage with irrigation canal priority
2C – Release storage with baseflow (WAC 173-548) priority

Alternative 3: Increase storage capacity by 2,298 AF using Pearrygin Lake and Patterson Lake only. Operational scenarios and priorities under this alternative were as follows:

3A – Release storage with ESA target flow priority
3B – Release storage with irrigation canal priority
3C – Release storage with baseflow (WAC 173-548)

A more detailed discussion of these alternatives is provided below.

4.3 Description of Alternative 1: Present Conditions

Alternative 1 is the No-Action alternative and represents the present conditions regarding storage, diversions, target levels and water priority.

4.3.1 Irrigation Diversions

Ten irrigation canal systems were simulated in the model. The simulations included diversion, seepage, spill, deliveries and return flows from each canal system. Table 4-2 shows the full supply requested by each canal system during the season. Table 4-3 shows the assumed seepage rates if the canals were at full supply. Each canal was assumed to spill 2% if at full supply. Delivery was simulated as the diversion less seepage and spill. The model assumed farm deliveries were 60% efficient. Four canal systems were split into sub-areas to allow seepage and deliveries to be split so river return flows could be more accurately represented. Seepage flows were split by canal length. Table 4-4 shows the canal lengths used in the model. Deliveries were split by acreage. Table 4-4 shows the acreages used in the model.

- Wolf Creek was simulated with one major diversion to the WCRD Patterson Lake feeder canal. The canal from Wolf Creek has a capacity of 12.5 cfs. This diversion is subject to a target flow of 8 cfs at the mouth of Wolf Creek (Table 4-1).

- The Chewuch River was simulated with three major diversions: Chewack Canal, Fulton Canal, and Skyline Canal. The full diversion request for each canal is shown in Table 4-2. Skyline Canal is subject to an ESA target flow of 80 cfs. When streamflow reaches the 80 cfs target flow, Chewack Canal is reduced by 2.5 cfs to allow Skyline a total of 5 cfs. Skyline Canal has a priority to 5 cfs over Chewack Canal and Fulton Canal. Chewack Canal and Fulton Canal have equal priority to water above the 5 cfs Skyline Canal flow.

- The Twisp River was simulated with two major diversions; TVPI Canal and MVID West Canal. A number of smaller diversions also exist on the Twisp River upstream of TVPI Canal; these diversions were simulated as one group called "Twisp Others". TVPI Canal and MVID West were simulated to have equal priority to water over "Twisp Others". (Table 4-2)

- The Methow River was simulated with three major diversions: FogHorn Canal, Barkley Canal, and MVID East Canal. The seasonal full supply diversion rates for each canal are in Table 4-2.

4.3.2 Storage

Two reservoirs are included in Alternative 1: Patterson Lake and Pearrygin Lake:

- Patterson Lake is operated by Wolf Creek Reclamation District (WCRD). WCRD has an annual storage right of 3065.6 AF for Patterson Lake. Patterson Lake has a natural inflow from Rader Creek. WCRD diverts water year round from Little Wolf Creek and seasonally (April to end of September) from Wolf Creek. Patterson Lake has an active capacity of 3,330 AF within the normal operational range of 25 feet. The surface area is approximately 125 acres at low pool and 150 acres at full pool. Patterson Lake was assumed to lose 1 cfs per day in seepage and 1.5 ft per year in evaporation.

- Pearrygin Lake is operated by Chewack Canal Company. Pearrygin Lake was assumed to have no measurable natural surface inflow. Chewack Canal Company has an annual storage right of 1,000 AF. Pearrygin Lake has an active capacity of 1,000 AF within the normal operational range of 5 feet. The surface area is assumed to be 200 acres at low pool and 210 acres at full pool. Pearrygin Lake seepage rate was assumed to be zero. Evaporation was estimated to be 1.5 feet per year.

4.3.3 Storage Reservoir Operations

Operational characteristics used in the model for each reservoir are as follows:

- Chewack Canal company attempts to fill Pearrygin by May 1 and diverts from the Chewuch River beginning April 1 at the rate shown in Table 4-2. Chewack Canal Company maintains a feeder canal to Pearrygin Lake that was simulated to have a capacity of 9 cfs. Currently Chewack Canal Company keeps Pearrygin Lake full until the beginning of August. Beginning in August, Chewack Canal Company lowers Pearrygin 2.5 feet by the end of each season if water is not used to meet demand below the lake. Pearrygin Lake water is released to the lower portion of the Chewack Canal via a natural drainage and feeder canal. It was assumed that the demands for the lower Chewack Canal sub-area were 18 cfs. If inflows to the Chewack Canal below the Pearrygin Lake return are lower than 18 cfs, then Pearrygin Lake was used to make up the difference.

- Water is released out the north end of Patterson Lake to a natural drainage for use lower in the drainage by WCRD for irrigation. The seasonal release pattern is shown in Table 4-5.

4.4 Alternative 2: Add 5,253 AF Storage to Basin (Pearrygin, Patterson, Elbow Coulee, Deadhorse Reservoir)

4.4.1 Irrigation Diversions

Existing diversions were simulated the same as in Alternative 1, with the following exceptions:

- The WCRD canal capacity was increased to 20 cfs.
- Unused Pearrygin Lake irrigation storage was allowed to carryover to the next year.

4.4.2 Storage

Alternative 2 simulates the additional basin storage of 5,253 AF used to maintain target flows in the Twisp and Chewuch Rivers. Patterson and Pearrygin Lakes were increased by 1,500 AF and 638 AF respectively. The Uphill Reservoir, with 160 AF of capacity, was added off of Skyline Canal. Elbow Coulee and Deadhorse Reservoirs were added in the Twisp River drainage, with capacities of 1,275 AF and 1,680 AF respectively. Table 4-6 is a summary of added storage simulated for Alternative 2.

4.4.3 Storage Reservoir Operations

4.4.3.1 Alternative 2A: Storage Release to ESA Target Flows

Diversions to fill the new storage are subject to ESA target flows. The added storage in Patterson Lake was moved from Patterson to fill Elbow Coulee Reservoir via a 20 cfs pipe. If Elbow Coulee Reservoir became full, water was put into Deadhorse Reservoir via the TVPI Canal. The additional storage in Patterson and Elbow Coulee and Deadhorse storage was released to the Twisp River to maintain a 40 cfs target flow (Table 4-1).

The additional Pearrygin Lake storage was released to the Chewuch River to maintain the 80 cfs target flow. Uphill Reservoir was used to maintain the Skyline Canal at 9.5 cfs.

4.4.3.2 Alternative 2B: Storage Release to Canals

Operations are the same as Alternative 2A with the following exceptions:

- Storage from Patterson Lake was released to the TVPI canal when Twisp River diversions would cause flows to drop below target flow requirements. TVPI diversions were reduced to allow others to meet demands.

- Storage from Pearrygin Lake was released to Chewack Canal when Chewuch River diversions would cause flows to drop below target flow requirements. Chewack Canal diversions were reduced to allow Skyline and Fulton Canals to maximize supply.

4.4.3.3 Alternative 2C: Storage Release to Washington State Baseflows

Storage was released to the river when any gage flow dropped below state baseflow requirements. No limit was put on releases. However, Uphill Reservoir was operated as in Alternative 2A, using the storage water to maintain 9.5 cfs in Skyline Canal.

4.5 Alternative 3: Add 2,298 AF Storage (Pearrygin, Uphill, and Patterson only)

4.5.1 Irrigation Diversions

Existing diversions were simulated the same as in Alternative 1, with the following exceptions:

- The WCRD canal capacity was increased to 20 cfs.
- Unused Pearrygin Lake irrigation storage was allowed to carryover to the next year.

4.5.2 Storage

This alternative operates the same as Alternative 2a, but has only 2,298 AF of added basin storage. The added storage is for Patterson and Pearrygin Lakes and Uphill Reservoir only. The added storage in Patterson Lake is diverted over to the Twisp River via Elbow Coulee. The diversion from Patterson Lake to Elbow Coulee was limited to 20 cfs.

4.5.3 Storage Reservoir Operations

4.5.3.1 Alternative 3A: Release to Target Flows

As in Alternative 2a the stored water is released directly to the river when the target flows are not met. Patterson Lake water is released via the canal on the north end of lake. No limit was put on releases.

Uphill Reservoir was operated the same as in Alternative 2.

4.5.3.2 Alternative 3B: Release to Canals

Storage water is released to TVPI Canal and Chewack Canal from Patterson and Pearrygin Lakes respectively.

Uphill Reservoir was operated the same as in Alternative 2.

4.5.3.3 Alternative 3C: Release to Washington State Baseflows

Storage is released directly to the river when state base flows downstream are not met. No limit was put on releases.

Uphill Reservoir was operated the same as in Alternative 2.

4.6 Model Results

Table 4-7 summarizes the results of the analysis.

4.6.1 Current Conditions

Under current conditions, the model predicts that water is available for storage as follows:

Gage	Available above ESA Targets (mean/minimum)	Available above WDOE Baseflows (mean/minimum)
Methow at Winthrop	NA	327,330 AF/39,300 AF
Methow at Twisp	NA	353,370 AF/31,640 AF
Methow at Pateros	NA	359,360 AF/25,340 AF
Chewuch at Winthrop	123,920 AF/9,430 AF	102,180 AF/1,420 AF
Twisp at Twisp	88,940 AF/18,910 AF	62,200 AF/9,040 AF
Wolf Creek at Winthrop	11,000 AF/1,710 AF	NA

Under current conditions, the model predicts that target flows or state baseflows are not met as follows:

Gage	Days and Volume Below ESA Targets	Days and Volume Below WDOE Baseflows
Methow at Winthrop	NA	28 days, 4,650 AF
Methow at Twisp	NA	103 days, 29,330 AF
Methow at Pateros	NA	123 days, 57,440 AF
Chewuch at Winthrop	49 days, 3,090 AF	90 days, 7,420 AF
Twisp at Twisp	39 days, 1,340 AF	106 days, 10,010 AF
Wolf Creek at Winthrop	NA	NA

Under current conditions, the model predicts that current streamflows and storage capacities do not cause significant shortfalls in irrigation deliveries for the Fulton, Chewuch, MVID, TVPI, Twisp Other, Foghorn and Barkley systems. The shortfalls predicted in the model (generally less than 3 days) are within the range of accuracy for the model. Shortfalls are present for Skyline (37 days) and WCRD (21 days) as a result of ESA target flow requirements.

4.6.2 Added Storage and Ability to meet ESA Target Flows

With the addition of storage, the ability to meet ESA target flows is improved:

- On the Chewuch, increased storage in Pearrygin Lake and Uphill Reservoir (Alternatives 2 and 3) reduces the number of days below ESA target flows from 49 days to 35 days if storage is released to meet target flows, and to 30 days if storage is released for canal delivery. The improvement to streamflow is greater when storage is used to meet canal delivery.

- On the Twisp (Alternative 2) storage in Patterson Lake, Elbow Coulee and Deadhorse Reservoir, reduces the number of days below target flows from 39 days to 6 days if storage is released to meet target flows, and to 12 days if storage is released for canal delivery. In this case, the improvement to streamflow is greater when storage is used to meet target flows.

- On the Twisp, if Elbow Coulee and Deadhorse Reservoir are not used (Alternative 3), the additional storage in Patterson Lake reduces the number of days below target flows from 39 days to 28 days if storage is released to meet target flows, and to 21 days if storage is released for canal delivery. In this case, the improvement to streamflow is greater when storage is used to meet target flows. This also shows that Elbow Coulee and Deadhorse Reservoir are important components of a storage system for the Twisp.

4.6.3 Added Storage and Ability to meet WDOE Baseflows

With the addition of storage, the ability to meet WDOE baseflows is improved only slightly. Storage reduces the number of days below WDOE baseflows by 3 days on the Methow River, 3 days on the Chewuch River, and 6 days on the Twisp River.

4.6.4 Added Storage and Ability to meet Canal Delivery

With the addition of storage, the ability to meet canal delivery requirements is improved for the Skyline and WCRD systems:

- For Skyline, increased storage in Pearrygin Lake and Uphill Reservoir reduces the number of days of irrigation delivery shortfall from 37 days to 24 days if storage is released to meet target flows, and to 20 days if storage is released for canal delivery.
- For WCRD, storage in Patterson Lake, Elbow Coulee and Deadhorse Reservoir, reduces the number of days of irrigation delivery shortfall from 21 days to 7 days if storage is released to meet target flows, and to 6 days if storage is released for canal delivery.

The addition of storage has some effect on the ability to meet delivery requirements at other irrigation canals depending on whether storage is released to meet target flows or for canal delivery:

- If storage is released directly to the river to meet target flows, the number of shortfall days remains essentially unchanged.

- If storage is released directly to canals during periods when target flows are not met, the number of shortfall days increases for Fulton, MVID west, and Twisp Other.

4.6.5 Storage Utilization

The maximum amount of storage present and the storage present at the end of the irrigation season provides an indication of how well storage is utilized. Utilization of each storage reservoir is described below:

- Pearrygin Lake, on average, reached 97% of its storage capacity when storage was used to release directly to the river to meet target flows. When storage is used to release directly to canals, Pearrygin Lake, on average, reaches 80% of its total storage capacity.
- September 30th storage volume on Pearrygin Lake is, on average, 1,120 AF (70% capacity) when storage is used release directly to the river to meet target flows. When storage is used

to release directly to canals, Pearrygin Lake, on average, is at 640 AF (40% capacity). More storage is used when it is used to release directly to canals.

- Patterson Lake, on average, reached 95% of its storage capacity when storage was used to release directly to the river to meet target flows. When storage is used to release directly to canals, Pearrygin Lake, on average, reaches 97% of its total storage capacity.
- September 30th storage volume on Patterson Lake is, on average, 3,030 AF (63% capacity) when storage is used release directly to the river to meet target flows. When storage is used to release directly to canals, Patterson Lake, on average, is at 3,160 AF (65% capacity). Similar storage amounts are used regardless of whether it is used to release directly to canals or directly to streams.

- Elbow Coulee, on average, reached 97% of its storage capacity when storage used to release directly to the river to meet target flows. When storage is used to release directly to canals, it also reaches 97% of its total storage capacity.
- September 30th storage volume in Elbow Coulee is, on average, 640 AF (50% capacity) when storage is used release directly to the river to meet target flows. When storage is used to release directly to canals, Elbow Coulee, on average, is at 810 AF (63% capacity). More storage is used when it is used to release directly to the river.

- Deadhorse Reservoir, on average, reached 81% of its storage capacity when storage used to release directly to the river to meet target flows. When storage is used to release directly to canals, it reaches 95% of its total storage capacity.
- September 30th storage volume in Deadhorse Reservoir is, on average, 1,200 AF (71% capacity) when storage is used release directly to the river to meet target flows. When storage is used to release directly to canals, Deadhorse Reservoir, on average, is at 1,540 AF (92% capacity). More storage is used when it is used to release directly to the river.

5.0 CONCLUSIONS AND RECOMMENDATIONS

The storage assessments conducted to date suggest that storage is a viable consideration and can provide measurable improvements in water availability in the Methow. Previous screening level studies (Klohn Leonoff, 1993) indicated a relatively low storage capacity (about 5,000 AF) from 24 sites using 40-foot dams, but recent analysis by the US Bureau of Reclamation suggests that 5,000 AF of additional capacity could be developed from only four sites (Pearrygin Lake, Patterson Lake, Elbow Coulee and Deadhorse Reservoir).

Integrated modeling of storage reservoirs and streamflow by the USBR indicates that both streamflows and irrigation delivery can be improved by increasing storage capacity and more prescriptive operational strategies. Specifically:

1. The ability to meet target flows on the Chewuch River and Twisp River is improved significantly.

2. The ability to meet WDOE baseflows is not improved significantly with the addition of storage to the basin.

3. The ability to meet irrigation delivery targets is either unchanged, improved slightly, or decreased slightly depending on location and whether storage is used to release directly to streamflow or used to release directly to canals.

Field analysis of groundwater storage by the USGS (see Appendix D) indicate that, of the six sites investigated, Big Twin Lake, Elbow Coulee, and the terrace south of Twisp are the best candidates for an artificial recharge program. The net volume of artificially recharged water that could be used at each of these sites could not be estimated with the data available and will require additional analysis.

In order for any of the storage projects considered in this analysis to proceed, additional work is needed to prepare environmental and cost/benefit analyses. Water rights for the proposed projects may not be the most critical issue, since both the USBR and USGS studies found that there was water available above instream flow requirements for all of the projects considered. Key issues to consider will therefore be:

- Criteria used to evaluate the potential benefit from each project. This would include an assessment of the priorities for use of the storage, which was shown to be important criteria in the USBR modeling.

- Land-ownership and land use issues. This assessment did not evaluate the “footprint” of the storage projects and associated land issues. It also did not evaluate who the “owner” of any of these storage projects would be.

- Engineering and geotechnical considerations. This assessment did not evaluate the constructability or cost of the various storage concepts.

- Permitting considerations. This assessment did not evaluate permitting issues. Conventional surface water storage projects have a complex, but relatively predictable permitting pathway. Artificial recharge projects could encounter permitting difficulties depending on how the use of the artificial recharge is specified in the permit applications.

TABLES

TABLE 1-1

Existing Reservoirs in the Methow River Basin Reproduced
From the Water Resources Management Program, Methow River Basin (December, 1976).

Reservoir Name	Stream Location	Storage (AF)	Surface Area (Acres)	Data Source
Patterson	Little Wolf Creek**	5,000	142.9	Lakes of Washington
Pearrygin	Chewack River (diversions)	1,000	192.0	Vol. II
Alta	None	Lake level maint.	187.4	Eastern Washington
Davis Lake	Bear Creek Drainage*	Approx. 200		

*Closed all year to further appropriations including added storage capacity
** Closed to additional diversions but development of future impoundments is allowed.

TABLE 1-2

Existing Dams in the Methow River Basin
Washington Department of Ecology, 1998

Dam Name	Stream Name	Owner Name	Purpose	Storage (AF)	Surface Area (Acres)
Hawkins Dam	Tr-Benson Creek		Irrigation	35	4
Chalfa Dam	Tr-Benson Creek		Irrigation	50	9
Wolf Creek Diversion Detention Dam	Wolf Creek Diversion Channel	Wolf Creek Reclamation District	Irrigation	8	8
Chewack Canal Diversion Dam	Chewack River	Chewuch Canal Company	Irrigation	2	2
Wright Ponds-West Pond Dam	Tr-Pearrygin Creek		Small Farm Pond	18	18
Moccasin Lake Dam	Tr-Thompson Creek-Offstream		Recreation	415	27
Patterson Lake Dam	Rader Creek	Wolf Creek Reclamation District	Recreation	3330	150
Rabel Dam	Tr-Benson Creek		Recreation	100	11
Beaver Lake Dam	Beaver Creek	Dept. of Agriculture, Forest Service	Recreation	60	31
Libby Lake Dam	North Fork Libby Creek	Dept. of Agriculture, Forest Service	Recreation	380	10
Davis Lake Dam	Tr-Bear Creek		Recreation	500	61
Sullivan Pond Dam	Tr-Chewack River	Washington Dept. of Wildlife	Recreation	30	30
Campbell Lake Dam	Tr-Beaver Creek	Washington Dept. of Wildlife	Recreation	50	11
Pearrygin Lake Dam	Lake Creek	Chewuch Canal Company	Recreation	1000	210
Wenner Lake No. 5 Dam	Tr-Benson Creek		Recreation	9	3
Peters Reservoir No. 2	Tr-Methow River		Recreation	12	3
Alder Gold-Copper Co Tailings Dam No. 1	Tr-Methow River	Alder Gold-Copper Company	Mine Tailings	50	50
Alder Gold-Copper Co Tailings Dam No. 2	Tr-Methow River	Alder Gold-Copper Company	Mine Tailings	22	22

TABLE 1-3

Potential Reservoirs in the Methow River Basin
Reproduced from the Water Surplus through Storage Report (Klohn Leonoff, 1993)

Site Name	Dam Base Elev. (feet)	Capacity		Drainage Area (sq miles)	Mean Annual Runoff (acre-ft)
		40’ Dam (acre-ft)	80’ Dam (acre-ft)		
Alder Creek	1,800	571	2,615	8.3	889
Bear Creek	2,280	64	470	15.3	4,078
Beaver Creek	1,920	269	1,665	83.0	29,217
Benson Creek	1,960	401	1,747	32.0	3,892
Black Canyon Creek	1,200	78	397	21.9	4,764
Boulder Creek	2,560	175	727	76.9	33,037
Chewuch River	3,720	342	2,226	96.0	114,649
Cow Creek	1,640	44	282	5.6	300
Crater Creek	5,520	53	346	3.1	2,179
Cub Creek	2,520	237	1,026	16.5	10,432
Eagle Creek	3,000	24	159	13.3	14,230
Eightmile Creek	2,520	714	3,582	42.6	30,794
Falls Creek	2,800	318	1,424	26.3	16,512
Foggy Dew Creek	4,800	114	549	11.9	8,332
French Creek	1,800	167	1,425	30.2	1,613
Goat Creek	2,680	98	464	31.5	25,160
Libby Creek	1,560	78	455	39.2	15,716
Lost River (Monument)	3,000	124	535	76.9	102,569
Lost River (Yellowjacket)	2,440	478	2,429	67.1	103,013
Martin Creek	5,000	52	261	6.5	4,938
McFarland Creek	2,040	370	1,401	10.1	2,702
Squaw Creek	1,760	79	467	12.1	3,216
Texas Creek	1,720	153	676	8.6	459
War Creek	3,280	39	220	24.9	30,942

TABLE 2-1

Washington State Regulatory Baseflows for the Methow Basin

Day/Month	Lower Methow	Middle Methow	Upper Methow	Methow Headwaters	Early Winters Creek	Chewuch River	Twisp River
1-Jan	350	260	120	42	10	56	34
15-Jan	350	260	120	42	10	56	34
1-Feb	350	260	120	42	10	56	34
15-Feb	350	260	120	42	10	56	34
1-Mar	350	260	120	42	10	56	34
15-Mar	350	260	120	42	10	56	34
1-Apr	590	430	199	64	14	90	60
15-Apr	860	650	300	90	23	140	100
1-May	1300	1000	480	130	32	215	170
15-May	1940	1500	690	430	108	290	300
1-Jun	2220	1500	790	1160	290	320	440
15-Jun	2220	1500	790	1160	290	320	440
1-Jul	2150	1500	694	500	125	292	390
15-Jul	800	500	240	180	45	110	130
1-Aug	480	325	153	75	20	70	58
15-Aug	300	220	100	32	8	47	27
1-Sep	300	220	100	32	8	47	27
15-Sep	300	220	100	32	8	47	27
1-Oct	360	260	122	45	11	56	35
15-Oct	425	320	150	60	15	68	45
1-Nov	425	320	150	60	15	68	45
15-Nov	425	320	150	60	15	68	45
1-Dec	390	290	135	51	12	62	39
15-Dec	350	260	120	42	10	56	34

TABLE 2-2

Difference Between Daily Streamflow and State Regulatory Baseflow for WY 1993-2002

Methow River above Goat Creek	319 cfs[1]
Chewuch River at Winthrop	287 cfs
Methow River at Winthrop	917 cfs
Twisp River at Winthrop	153 cfs
Methow River at Twisp	855 cfs
Methow River near Pateros	781 cfs

[1]Cubic feet per second

TABLE 2-3

Annual Volume of Streamflow in Excess of WA Regulatory Baseflows
Negative Values Indicate That Annual Was Less Than Regulatory Baseflow

Water Year	Methow River above Goat Creek	Chewuch River at Winthrop	Methow River at Winthrop	Twisp River near Twisp	Methow River at Twisp	Methow River near Pateros
1992	159	80	443	51	360	244
1993	288	118	403	44	297	199
1994	73	122	362	31	263	4156
1995	293	300	859	168	880	801
1996	365	302	951	218	998	946
1997	391	339	1000	200	1003	999
1998	292	288	844	135	820	844
1999	443	374	1065	170	1036	1088
2000	227	160	586	101	556	501
2001	-24	-8	124	-6	-22	-124

TABLE 2-4

Number of Days Each Water Year (WY) When
Streamflow Exceeded Regulatory Baseflows

Water Year	Methow River above Goat Creek	Chewuch River at Winthrop	Methow River at Winthrop	Twisp River near Twisp	Methow River at Twisp	Methow River near Pateros
1992	179	321	366	312	324	216
1993	106	196	337	211	130	116
1994	94	286	365	158	157	89
1995	198	285	366	335	234	220
1996	321	365	365	366	366	358
1997	193	365	365	365	361	333
1998	250	365	365	354	354	364
1999	189	365	365	365	310	325
2000	247	350	366	354	351	353
2001	26	85	326	152	66	15
Median	189	321	365	335	310	220

TABLE 2-5

Annual Volume of Streamflow in Excess of Regulatory Baseflow
For Days When Streamflow Exceeded Regulatory Baseflows

Water Year	Methow River above Goat Creek	Chewuch River at Winthrop	Methow River at Winthrop	Twisp River near Twisp	Methow River at Twisp	Methow River near Pateros
thousands of acre feet						
1992	174	81	444	55	362	259
1993	122	127	408	53	347	301
1994	105	124	362	41	279	215
1995	308	301	859	169	894	826
1996	370	303	953	218	1001	949
1997	403	339	1000	200	1003	1001
1998	297	288	844	135	821	844
1999	460	374	1065	170	1039	1090
2000	232	160	588	101	558	503
2001	25	9	133	12	55	32

TABLE 4-1

Modeled Target Flows

Date	Wolf Creek	Chewuch River
1-Jan	0 cfs	0 cfs
1-Feb	0 cfs	0 cfs
1-Mar	0 cfs	0 cfs
1-Apr	8 cfs‡	80cfs†
16-Apr	8 cfs‡	80cfs†
1-May	8 cfs‡	80cfs†
1-Jun	8 cfs‡	80cfs†
1-Jul	8 cfs‡	80cfs†
1-Aug	8 cfs‡	80cfs†
16-Aug	8 cfs‡	80cfs†
1-Sep	8 cfs‡	80cfs†
16-Sep	8 cfs‡	80cfs†
1-Oct	8 cfs‡	80cfs†
1-Nov	0 cfs	0 cfs
1-Dec	0 cfs	0 cfs

Note:

† Skyline Canal diversion rates are dependant on the discharge in the Chewuch River meeting ESA target baseflows. During irrigation season, when the flow in the Chewuch River is greater than 80 cfs, the diversion rate is 17 cfs. If the flow in the Chewuch River drops below 80 cfs, the diversion rate to the Skyline Canal is reduced to 2.5 cfs. Also, when the flow in the Chewuch River falls below 80 cfs, the diversion to the Chewack Canal is reduced by 2.5 cfs and this water is diverted by Skyline. At the 80 cfs target Skyline may divert a total of 5 cfs.

‡ WCRD Canal diversions are subject to the ESA target baseflows on Wolf Creek. When the gage on Wolf Creek indicates the discharge is less than 8 cfs the WCRD Canal is closed.

TABLE 4-2

Modeled Canal Diversion Rates

Date	Fulton Canal	Chewuch Canal	Skyline Canal	MVID West Canal	TVPI Canal	Twisp Others	Fog Horn Canal	MVID East Canal	Barclay Canal	WCRD Canal
1-Jan	0 cfs	0 cfs	0 cfs	0 cfs	0 cfs	0 cfs	0 cfs	0 cfs	0 cfs	0 cfs
1-Feb	0 cfs	0 cfs	0 cfs	0 cfs	0 cfs	0 cfs	0 cfs	0 cfs	0 cfs	0 cfs
1-Mar	0 cfs	0 cfs	0 cfs	0 cfs	0 cfs	0 cfs	0 cfs	0 cfs	0 cfs	0 cfs
1-Apr	0 cfs	12 cfs	0 cfs	0 cfs	0 cfs	0 cfs	0 cfs	0 cfs	0 cfs	0 cfs
16-Apr	0 cfs	12 cfs	0 cfs	0 cfs	0 cfs	0 cfs	0 cfs	0 cfs	0 cfs	0 cfs
1-May	14 cfs	31 cfs	See note †	29 cfs	14 cfs	10 cfs	14 cfs	24 cfs	12 cfs	0 cfs
16-May	14 cfs	31 cfs	See note †	29 cfs	14 cfs	10 cfs	14 cfs	24 cfs	12 cfs	5 cfs‡
1-Jun	14 cfs	31 cfs	See note †	29 cfs	14 cfs	10 cfs	15 cfs	24 cfs	18 cfs	9.6 cfs‡
16-Jun	14 cfs	31 cfs	See note †	29 cfs	14 cfs	10 cfs	15 cfs	24 cfs	18 cfs	9.6 cfs‡
1-Jul	14 cfs	31 cfs	See note †	29 cfs	14 cfs	10 cfs	15 cfs	24 cfs	18 cfs	10.1 cfs‡
16-Jul	14 cfs	31 cfs	See note †	29 cfs	14 cfs	10 cfs	15 cfs	24 cfs	18 cfs	10.1 cfs‡
1-Aug	14 cfs	31 cfs	See note †	29 cfs	14 cfs	10 cfs	15 cfs	24 cfs	15 cfs	9.6 cfs‡
16-Aug	14 cfs	31 cfs	See note †	29 cfs	14 cfs	10 cfs	15 cfs	24 cfs	15 cfs	9.6 cfs‡
1-Sep	14 cfs	31 cfs	See note †	29 cfs	14 cfs	10 cfs	15 cfs	24 cfs	9 cfs	8 cfs‡
16-Sep	14 cfs	31 cfs	See note †	29 cfs	14 cfs	10 cfs	15 cfs	24 cfs	9 cfs	8 cfs‡
1-Oct	0 cfs	0 cfs	0 cfs	0 cfs	0 cfs	0 cfs	0 cfs	0 cfs	0 cfs	0 cfs
1-Nov	0 cfs	0 cfs	0 cfs	0 cfs	0 cfs	0 cfs	0 cfs	0 cfs	0 cfs	0 cfs
1-Dec	0 cfs	0 cfs	0 cfs	0 cfs	0 cfs	0 cfs	0 cfs	0 cfs	0 cfs	0 cfs

Note:

† Skyline Canal diversion rates are dependent on the discharge in the Chewuch River meeting ESA target baseflows. During irrigation season, when the flow in the Chewuch River is greater than 80 cfs, the diversion rate is 17 cfs. If the flow in the Chewuch River drops below 80 cfs, the diversion rate to the Skyline Canal is reduced to 2.5 cfs. When the flow in the Chewuch River falls below 80 cfs, the diversion to the Chewack Canal is reduced to 28.5 and the 2.5 cfs is diverted by Skyline Canal.

‡ WCRD Canal diversions are subject to the ESA target baseflows on Wolf Creek. When the gage on Wolf Creek indicates the discharge is less than 8 cfs the WCRD Canal is closed.

TABLE 4-3

Modeled Canal Seepage Rates

Canal	Seepage Rate
Barkley	50%
Chewuch	50%
Foghorn	50%
Fulton	50%
MVID East	55%
MVID West	61%
Skyline	0%
TVPI	50%
Twisp Others	50%
WCRD	0%

Note: These estimates are based on measurements made by USGS and adjusted by USBR.

TABLE 4-4

Modeled Acreage and Canal Length Used to Split Deliveries and Seepage for Each Canal

Canal	Acreage Irrigated	Canal Length
Chewuch 1	300	2.1
Chewuch 2	980	8.8
TVPI 1	50	2.2
TVPI 2	450	1.7
MVID West 1	375	3.3
MVID West 2	375	8.2
MVID East 1	150	5.3
MVID East 2	600	5.8

TABLE 4-5

Modeled Releases from Patterson Lake to the
Wolf Creek Reclamation District.

Date	Patterson Lake Release to WCRD
1-Jan	0 cfs
1-Feb	0 cfs
1-Mar	0 cfs
1-Apr	0 cfs
16-Apr	0 cfs
1-May	0 cfs
16-May	8.7 cfs
1-Jun	9.7 cfs
16-Jun	9.7 cfs
1-Jul	10.4 cfs
16-Jul	10.4 cfs
1-Aug	10 cfs
16-Aug	10 cfs
1-Sep	8 cfs
16-Sep	8 cfs
1-Oct	0 cfs
1-Nov	0 cfs
1-Dec	0 cfs

TABLE 4-6

Reservoir Storage Volumes Used in Model Evaluation.

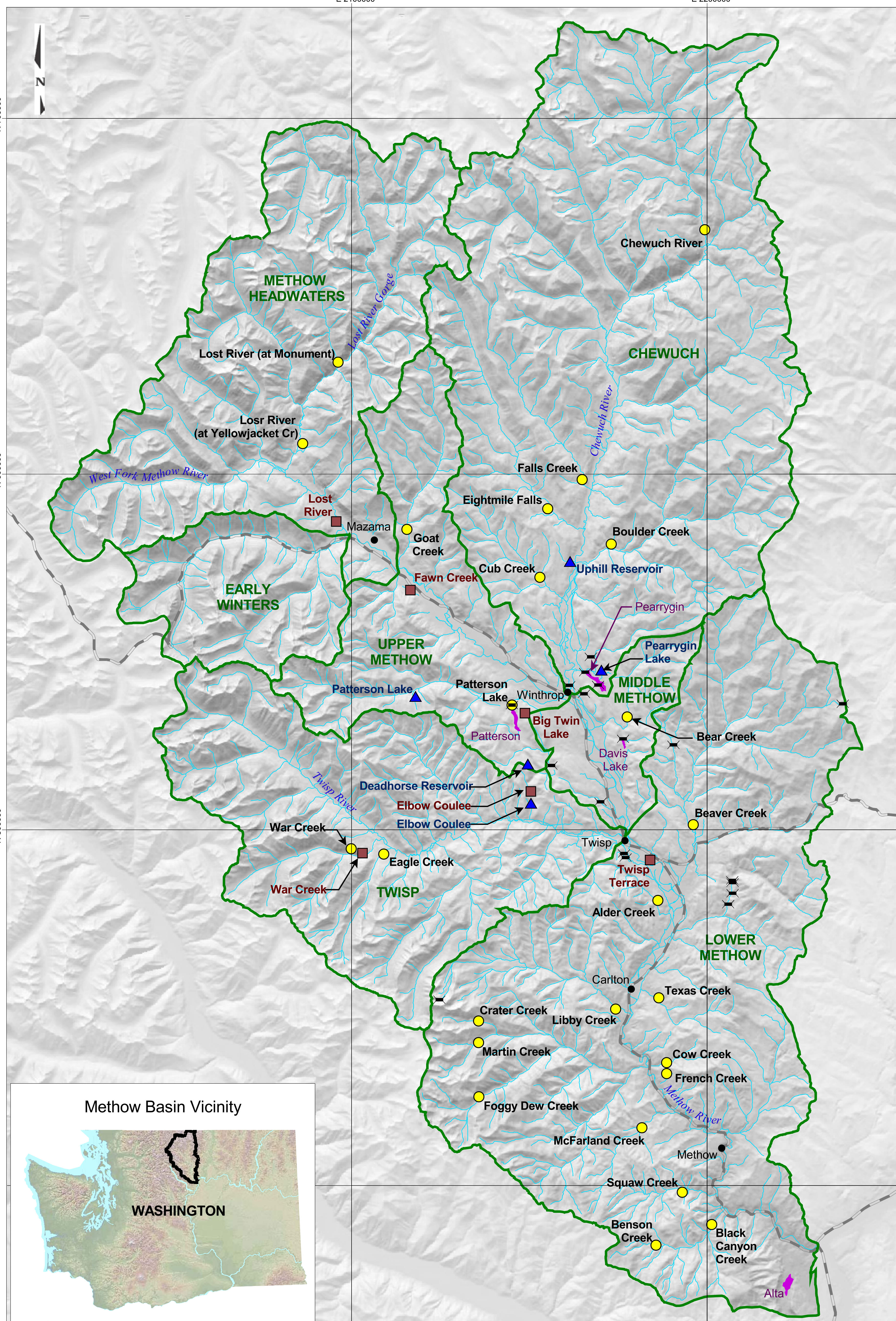
Reservoir Name	Added Depth (feet)	Volume (acre-feet)
Patterson	10	1500
Pearrygin	3	638
Elbow Coulee	N/A	1275
Deadhorse	N/A	1680
Uphill	N/A	160

TABLE 4-7

Summary of RiverWare Modeling Results

	Alternative 1 - Present Condition - 4,330 AF Existing Storage				Alternative 2 - 5,253 AF New Storage			Alternative 3 - 2,298 AF New Storage		
					2a : Release to River Target Flows	2b : Release to Canal	2c : Release to River WDOE Baseflows	3a : Release to River Target Flows	3b : Release to Canal	3c : Release to River WDOE Baseflows
	Annual Available for Storage		Average Annual Flow Shortage							
Streamflow Conditions	**Target Flow**	**WDOE Baseflow**	**Target Flow**	**WDOE Baseflow**	**Target Flow**		**WDOE Baseflow**	**Target Flow**		**WDOE Baseflow**
Methow @ Winthrop		Ave 327,330AF Min 39,300AF		28 Days 4,650AF			27 Days 4,630AF			27 Days 4,630AF
Methow @ Twisp		Ave 353,370AF Min 31,640AF		103 Days 29,330AF			100 Days 28,910AF			102 Days 29,170AF
Methow @ Pateros		Ave 359,360AF Min 25,340AF		123 Days 57,440AF			120 Days 55,610AF			122 Days 56,270AF
Chewuch @ Winthrop	Ave 123,920AF Min 9,430AF	Ave 102,180AF Min 1,420AF	49 Days 3,090AF	90 Days 7,420AF	35 Days 2,660AF	30 Days 1,320AF	87 Days 7,130AF	35 Days 2,660AF	30 Days 1,320AF	86 Days 7,100AF
Twisp @ Twisp	Ave 88,940AF Min 18,910AF	Ave 62,200AF Min 9,040AF	39 Days 1,340AF	106 Days 10,010AF	6 Days 250AF	12 Days 170AF	101 Days 9,260AF	28 Days 1,100AF	21 Days 290AF	106 Days 10,010AF
Wolf @ Winthrop	Ave 11,000AF Min 1,710AF									
	Alternative 1 - Present Condition - 4,330 AF Existing Storage				**Alternative 2 - 5,253 AF New Storage**			**Alternative 3 - 2,298 AF New Storage**		
					2a	**2b**	**2c**	**3a**	**3b**	**3c**
Canal Conditions	**Average Annual Irrigation Delivery Shortage**									
Fulton	1 Day 1AF				1 Day 1AF	26 Days 570AF	1 Day 1AF	1 Day 1AF	26 Days 570AF	1 Day 1AF
Chewack	1 Day 14AF				7 Days 5AF	7 Days 270AF	7 Days 5AF	7 Days 5AF	7 Days 270AF	7 Days 5AF
Skyline	37 Days 320AF				24 Days 210AF	20 Days 180AF	24 Days 210AF	24 Days 210AF	20 Days 180AF	24 Days 210AF
MVID East	1 Day 5AF				1 Day 5AF	0 Days 0AF	1 Day 5AF	1 Day 5AF	0 Days 0AF	1 Day 5AF
MVID West	0 Days 0AF				0 Days 0AF	14 Days 390AF	0 Days 0AF	0 Days 0AF	19 Days 670AF	0 Days 0AF
TVPI	3 Days 9AF				3 Days 9AF	0 Days 0AF	3 Days 9AF	3 Days 9AF	18 Days 150AF	3 Days 9AF
Twisp Other	9 Days 130AF				9 Days 130AF	21 Days 350AF	9 Days 130AF	9 Days 130AF	22 Days 400AF	9 Days 130AF
Foghorn	0 Days 0AF				0 Days 0AF	0 Days 0AF	0 Days 0AF	0 Days 0AF	0 Days 0AF	0 Days 0AF
Barkley	0 Days 0AF				0 Days 0AF	0 Days 0AF	0 Days 0AF	0 Days 0AF	0 Days 0AF	0 Days 0AF
WCRD	21 Days 360AF				7 Days 120AF	6 Days 100AF	13 Days 230AF	3 Days 60AF	3 Days 60AF	13 Days 220AF
	Alternative 1 - Present Condition - 4,330 AF Existing Storage				**Alternative 2 - 5,253 AF New Storage**			**Alternative 3 - 2,298 AF New Storage**		
					2a	**2b**	**2c**	**3a**	**3b**	**3c**
Storage Conditions	**Average Annual Maximum 4/1-7/31 Storage and Average Annual Sept 30th Storage**									
Pearrygin Lake	990AF 350AF				1,590AF 1,120AF	1,300AF 640AF	1,530AF 1,060AF	1,590AF 1,120AF	1,300AF 640AF	1,530AF 1,060AF
Patterson Lake	3,380AF 2,170AF				4,570AF 3,030AF	4,700AF 3,160AF	4,200AF 2,580AF	4,870AF 3,250AF	4,880AF 3,260AF	4,680AF 2,800AF
Uphill Reservoir	NA				160AF 50AF	160AF 60AF	160AF 50AF	160AF 50AF	160AF 60AF	160AF 50AF
Deadhorse Reservoir	NA				1,370AF 1,200AF	1,590AF 1,540AF	550AF 520AF	NA	NA	NA
Elbow Coulee Reservoir	NA				1,240AF 640AF	1,250AF 810AF	1,090AF 420AF	NA	NA	NA

FIGURES



LEGEND

- Sub-basin Boundaries
- Towns
- Highways
- Streams
- Existing Dams (WSDOE, 1998)
- USGS 2002 Groundwater Storage Sites
- USBR Storage Sites (Riverware Modelling)
- Potential Reservoirs (Klonn Leonoff, 1993)
- Existing Reservoirs (WSDOE, 1976)

0 5

Scale 1" = 5 Miles

Map Projection: Washington State Plane North NAD 27, Feet

Source: Washington Department of Ecology, USGS

DRAFT

Methow Basin
Proposed / Existing Dams and Reservoirs

OC/METHOW PH III WATERSHED PLAN/WA

Drawn: GKL	Revision:	Date: Oct 8, 2003	Figure: **1-1**

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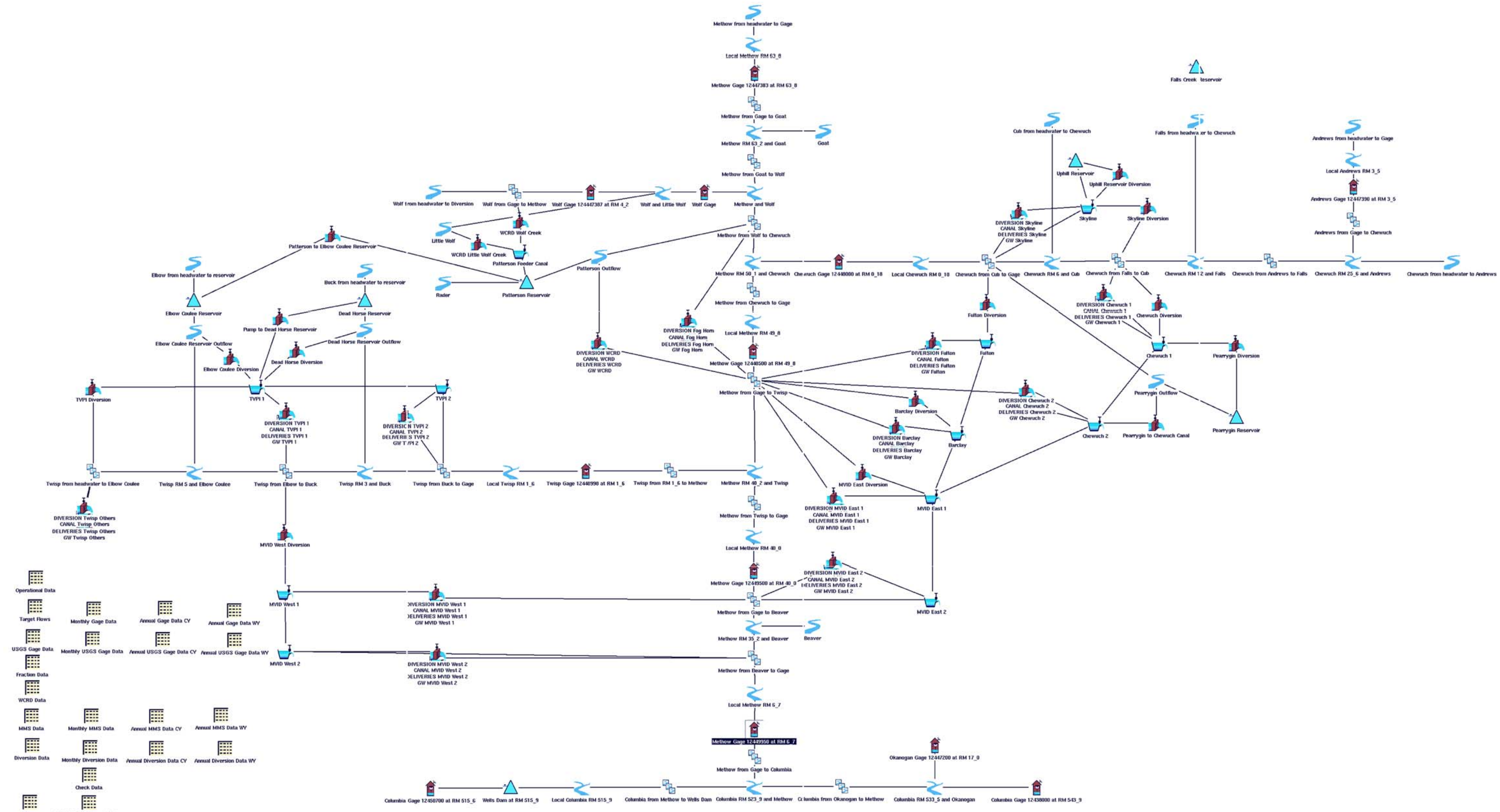

Source: US Bureau of Reclamation, 2003

FIGURE **4-1**
METHOW SUB-BASIN RIVERWARE NETWORK
OC/METHOW BASIN WATERSHED ASSESS/WA

DRAWING NO. 0231244009fg01.fh11 DATE 10/08/03 DRAWN BY AMP

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APPENDIX A

WATER STORAGE TASK FORCE REPORT TO LEGISLATURE (2001)

Water Storage Task Force

Summary | Final Report | Background Info | Related Issues | Meeting Presentations | Links | More Info

Summary ▲

The Water Storage Task Force was convened by the Washington State Department of Ecology (Ecology) at the direction of the 2000 state legislature. The Task Force examined the role of increasing water storage to provide water for fish recovery, population and economic growth, and flood control. The Task Force also considered funding options for constructing water-storage facilities.

The Task Force was formed to examine issues and frame recommendations for the legislature. Members represented water utility districts, agriculture associations, city and county associations, Indian tribes, legislators, environmental interests, and state agencies.

Final Report ▲

- Water Storage Task Force Report to the Legislature
- Water Storage Task Force Report to the Legislature: Appendices

Background Information ▲

- 2000 Legislative Budget Proviso Language (5K PDF File)
- Updated List (September 2000) of Water Storage Task Force Members (14K PDF File)

Related Issues ▲

- Washington State Laws Related to Water Storage (91K PDF File)
- Local Government Infrastructure Study (55K PDF File)
- Memorandum of Agreement Regarding Utilization of Skagit River Basin Water Resources for Instream and Out of Stream Purposes (56K PDF File)
- Referendum 38 Projects: 1980 to Present (15K PDF File)
- Existing and Potential Reservoir Sites in the Methow-Okanogan, and Chelan-Wenatchee-Entiat Basins, 1975 (718K PDF File)
- Comparative Cost Data for Raises of Existing Dams (7K PDF File)
- Potential Dam & Reservoir Sites Identified in Level B Studies, 1976-77, by the Pacific Northwest River Basin Commission (11K PDF File)
- Survey and Analysis of Water and Wastewater Infrastructure Financing Mechanisms, prepared for the Texas Water Development Board (4,008K PDF File)
- Washington Department of Fish & Wildlife Policy: Requiring or Recommending Mitigation (24K PDF File)
- Effects of Geologic and Hydrologic Factors and Watershed Change on Aquatic Habitat in the Yakima River Basin (25K PDF File)

- Chapter 2 on: "Normative River" excerpted from "Return to the River: Restoration of Salmonid Fisheries in the Columbia River Ecosystem" (24K PDF File)

Meeting Presentations ▲

- Review of Presentations from August 1, 2000 Meeting (14K PDF File)
- Review of Presentations from September 11, 2000 Meeting (16K PDF File)
- Excerpts from the U.S. Forest Service Aquatic Conservation Strategy (8K PDF File)
- Why Store Water? (145K PDF File)
- Dams: On Channel, Off Channel, New Dams vs. Enlargement of Existing, Costs (2,474K PDF File)
- Flood Control: Regional Scale Facilities (245K PDF File)
- Flood Control: Small Scale Stormwater Facilities (232K PDF File)
- Aquifer Storage and Recovery: Lakehaven Project (357K PDF File)
- Judy Reservoir: An Off-Stream Water Storage Project (2,538K PDF File)
- Becoming Climate-Wise with Washington's Water (264K PDF File)

Links ▲

- The National Council for Science and the Environment: Western Water Resources Issues, May 19, 2000
- Department of Ecology Dam Safety Office
- Offstream Storage in California

More Information ▲

If you have questions regarding Water Storage Task Force activities, please contact Christine Corrigan. Ms. Corrigan can be reached by telephone at (360) 407-6607 or by email at csun461@ecy.wa.gov.

Last Update: August 31, 2000
Comments or questions regarding this page? Contact Us!

Water Storage Task Force

Report to the Legislature

February 2001

WASHINGTON STATE DEPARTMENT OF ECOLOGY

Publication No. 01-11-002

Water Storage Task Force

Report to the Legislature

Prepared by
Water Resources Program
Washington State Department of Ecology
under the direction of
The Water Storage Task Force

Cover photo: Judy Reservoir, Skagit County

February 2001
Publication No. 01-11-002

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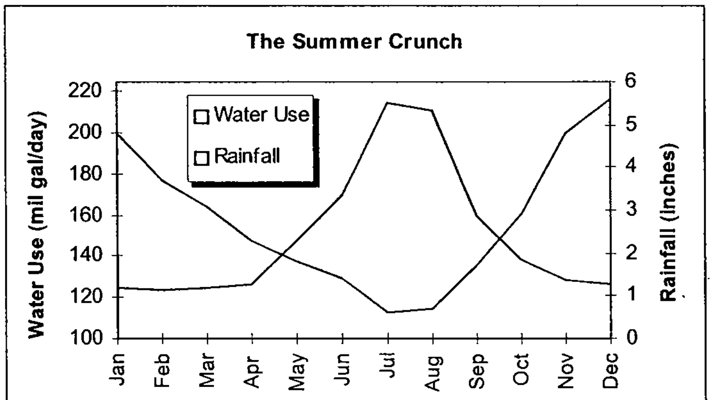
Table of Contents

The Need for Storage

Compared to many of the western states, the state of Washington would seem to have plenty of water. This water, however, is not distributed evenly across the state, nor is it available at all times of the year. Differences in climate result in an annual precipitation of over 200 inches on the coast, and less than eight inches in some areas of Eastern Washington. Furthermore, most of our precipitation comes in the late fall and winter, when demand is lowest. In the summer, when precipitation and stream flows are at their lowest, the demand for water is at its highest. Figure 1 illustrates the seasonal changes in rainfall and municipal water use in the Seattle area.



This chart shows that water availability and water use are mirror images. Water use is highest when water availability is lowest, creating a summer water supply "crunch."

FIGURE 1. *Source:* Seattle Public Utilities 1998 Accomplishment Report

The demand for water in Washington is increasing. A growing state population, a healthy economy and declines in salmon populations have each created a call for increased water supplies. These supplies are not readily available in many parts of the state, especially during the dry season. Today, approximately 350 lakes and streams in Washington are closed to further withdrawals of water. Approximately 100 more streams are partially closed, and 200 streams have stream flows set by rule. The needs for water have sharpened the competition for available supplies and have added a new urgency to the need to secure additional water supplies.

Growth and economic development have been stalled in cities and counties that don't have access to additional water. The cities of Battle Ground, North Bend, Lynden, Granger, Warden, Cle Elum, Tieton, and East Spokane are among the many communities searching for more water.

Rural economic development is also stifled by lack of water. Farmers in the Tucannon River and Pataha Creek drainages have asked for more water in an area that already doesn't have enough water to serve current requests. In Snohomish County, a large, new organic farm was recently told it could not get a new water right, as the area does not have enough water for current uses.

In many parts of the state, fish are at risk of becoming extinct, in part because they don't have enough water. There are many streams where flows are considered to be too low for fish in the summer and fall. This problem exists in streams on both sides of the Cascades and is an issue in most of the counties of the state. In addition, as we look to the future, climate models by the University of Washington indicate the potential for even less snow pack and lower summer flows over the next decade or two.

One solution for the state's water supply problem is to store water when there is excess runoff and stream flows, and deliver or release it during the low-flow period when it is needed for people and fish.

Task Force: Purpose and Process

During the 2000 legislative session, the Legislature recognized the potential for additional water storage as a solution to the water supply needs of the state. As a result, the following proviso was included in the 2000 supplemental operating budget (Chapter 1, Laws of 2000, Engrossed House Bill 2487):

> *Section 301(27). $150,000 of the general fund state appropriation for fiscal year 2001 is provided solely for creating the task force on water storage.* ***The purpose of the task force is to examine the role of increased water storage in providing water supplies to meet the needs of fish, population growth, and economic development, and to enhance the protection of people's lives and their property and the protection of aquatic habitat through flood control facilities.*** *For this purpose, increased storage may be in the form of surface storage including off-stream storage, underground storage, or the enlargement or enhancement of existing structures. The task force shall also examine means of providing funding for increased water storage.*
>
> *The department of ecology shall provide staff support for the task force and the director of the department of ecology shall convene the first meeting of the task force not less than thirty days after the effective date of this section.*
>
> *No member of the task force shall receive compensation, per diem, or reimbursement of expenses from the task force or the department of ecology for his or her activities as a member of the task force. However, each may receive such compensation, per diem, and/or reimbursement as is authorized by the entity he or she is employed by, is appointed from, or represents on the task force.*
>
> *Following its examination, the task force shall report its recommendations to the appropriate committees of the legislature by December 31, 2000.* (emphasis added)

In response to this proviso, Ecology invited agencies, organizations and individuals with a range of interests in water storage to provide representatives to serve on a Water Storage Task Force. From this invitation process, the following individuals were nominated to serve:

Bob Alberts, Pasco Public Works Department, representing WA Water Utility Council and Association of Washington Cities
John Bowman, Lakehaven Utility District
Dueane Calvin, City of Yakima
Walt Canter, Washington Association of Water and Sewer Districts
Representative Gary Chandler, House Agriculture & Ecology Committee
Lee Faulconer, Department of Agriculture
Tom Fitzsimmons, Department of Ecology, Water Storage Task Force Chairman
Senator Karen Fraser, Senate Environmental Quality & Water Resources Committee
Steve George, Hops Growers of Washington

Max Golladay, Kittitas County Commissioner, representing Washington Association of Counties, Eastern Washington
Jim Hazen, Washington State Horticultural Association
Representative Kelli Linville, House Agriculture & Ecology Committee
Ken Lisk, Washington State Water Resources Association
John Mankowski, Washington Department of Fish and Wildlife
Senator Bob Morton, Senate Environmental Quality & Water Resources Committee
Bob Pancoast, East King Co. Regional Water Association, representing Washington Water Utility Council, Western Washington
Tom Ring, for Harris Teo, Jr., Yakama Nation
Mike Schwisow, Washington State Water Resources Association
Dave Somers, Snohomish County Commissioner, representing Washington Association of Counties, Western Washington
Ginny Stern, Washington Department of Health
Judy Turpin, Washington Environmental Council

Five all-day meetings of the task force were held. Press releases were issued prior to each meeting, and the public and media were invited to attend and observe meetings. The schedule and locations of the meetings were as follows:

1. August 1, 2000	Hyak Lodge at Snoqualmie Pass
2. September 11, 2000	Mount Vernon, Skagit PUD offices
3. October 5, 2000	Ellensburg, Hal Holmes Conference Center
4. November 9, 2000	Bellevue, Ecology's Northwest Regional Office
5. December 7, 2000	Lacey, U.S. Fish and Wildlife Service

The first two meetings were organized by Ecology staff to provide information to the task force on issues surrounding storage. Presentations were made by task force members, outside parties and Ecology staff having expertise in various water issues. Appendix A contains summaries for the presentations given during the initial meetings. Ecology also presented a draft outline for the task force report at the second meeting.

Meeting 3 largely involved discussing the issues, previous presentations and contents of the report. The task force began forming conclusions and recommendations during this meeting. Detailed discussion and editing of each recommendation was done during Meeting 4. The recommendations were reviewed, and the conclusions were discussed and completed during Meeting 5.

Reasons for Storing Water

Water can be stored to serve many different purposes, including supplies for domestic needs, municipal uses, agricultural irrigation, and fish and wildlife needs. Water storage also helps control floods, generate power and serve recreational needs. Many of the state's existing storage projects serve more than one purpose. The most common combinations for larger projects in Washington are:

- Irrigation, recreation and wildlife.
- Hydropower generation and flood control.

Increasing demand and decreasing natural storage are the major reasons for the call for increased water storage in this state.

Increasing demand

State population has grown from 1.5 million to over 5 million in the last 80 years, and is estimated to reach 7 million by the year 2010.

- Population growth increases the need for domestic water supplies, commercial and industrial water supplies, power generation and food production.

- Fish populations are in decline in a number of streams and rivers. All but one county in the state has a salmon, trout and/or steelhead species with a current Endangered Species Act designation. ESA listings have spurred the call for increased stream flows to assist in the recovery of these species.

Decreasing natural storage

Water stored under ground and water in the form of snow represent the largest sources of stored water in the state: "natural storage." This naturally stored water is often the only source of stream flows during the late summer and early fall, as the snow melts and the ground releases water to maintain surface streams. Underground water (also called ground water) is also the only source of water for many communities around the state.

- Loss of ground-water recharge. Urbanization that creates larger areas with impervious surfaces will divert storm flows and decrease ground-water recharge. Development that narrows the floodplain will reduce the recharge of ground water that would normally occur during routine flooding.

- Climate change. Most scientists agree that the earth is warming, either from natural causes and/or increased greenhouse-gas emissions from human activity. A small increase in temperature would result in less snow and an earlier melt, reducing the natural storage benefits of the snow pack and producing higher flows in the spring and lower flows in the late summer. A small increase in temperature will also raise the freezing level. Some areas that currently have a snow pack may no longer have any snow after the winter months.

Methods for Storing Water

Storing water can be done in several ways. Water can be stored above ground in a surface-water reservoir, usually behind a dam. Water can also be stored underground in aquifer storage and recovery sites.

Surface Water Reservoirs

- The most common method for storing water is creating a surface reservoir behind some sort of dam or dike.

- There are currently more than 1,100 dams in Washington State that store more than 10 acre-feet, with about 380 dams used primarily for water supply storage. However, most projects are rather small, and only 80 dams are greater than 50 feet in height.

- On-channel dams and reservoirs are sited on major streams and are filled directly by flow from the upstream watershed. These are typically large projects that impound many thousands of acre-feet of water.

- Off-channel dams are sited outside the main river valley, on an intermittent stream or completely off-stream. There is typically minimal inflow provided by the tributary drainage. Water to fill the reservoir is usually diverted by gravity or pumping from a much larger adjacent basin.

- New dams can be built to create new water reservoirs, or existing reservoirs can be enlarged by raising existing dams.

Aquifer Storage and Recovery

- Aquifer storage and recovery is defined as capturing usable excess water and storing it underground for later use.

- Potential sources of water for underground storage include excess surface water in winter, stormwater runoff, and high-quality, treated/reclaimed water.

- Methods for getting water into aquifer storage include direct injection via wells, surface spreading by irrigation or use of ponds, and infiltration by piping the water just beneath the land surface.

- Recovering the stored water is typically done by using wells. Under the right conditions, aquifer recharge can also be done to help recover base flows for a nearby stream, spring, or wetland.

- Unlike surface reservoirs, aquifer storage does not require significant commitment or changes in use of the land surface.
- Aquifer storage may restore declining water levels due to over-withdrawals from the aquifer.
- Aquifer storage has the potential to improve water quality of native underground water.
- Aquifer storage requires locating an aquifer in a geologic formation where most of the water will stay in place long enough for it to be recovered.
- Reclaimed water shows promise as a source of "new" water for storage in underground reservoirs, but there remain public perception issues with potential contamination of ground waters.

The major benefits and drawbacks of these water storage methods are outlined in Table 1.

Table 1: Comparison of Different Methods of Storage

Benefits	Drawbacks
New On-Channel Dams	
• Large reservoirs can be filled by direct runoff from the drainage basin using the stream as the conveyance system. • Can provide substantial flood control benefit. • Usually less expensive construction, operations and maintenance costs than for large off-channel reservoirs.	• Can requires relocation of people and infrastructure. • Can drown significant riparian habitat. • Barrier to fish passage. • Sediment load can eventually fill in reservoir. • Requires large spillways and outlet works.
New Off-Channel Dams	
• Generally do not represent a barrier to fish passage. • Can be sited in a non-environmentally sensitive area, and may not require extensive mitigation. • Less water quality harm on main river than for on-channel dams • Much smaller spillways and outlet works needed.	• Require extensive conveyance infrastructure (canals, pipes) to get water into and out of reservoir. • Construction, operations and maintenance costs can be much higher than on-channel reservoirs. • Leakage and seepage may require a liner to be placed in the reservoir.
Raise Existing Dams	
• New environmental effects are relatively fewer and smaller compared to a new dam. • The unit cost for increased water storage is typically much lower than for new dam projects. • Significant storage volume can typically be added for a relatively small increase in dam height.	• Existing development around the reservoir has to be relocated or purchased. • Potential risk to downstream lives and property increased, may require extensive dam safety upgrading. • Wetlands and riparian habitats created by the existing reservoir may be displaced.
Aquifer Storage & Recovery	
• Minimal construction is required. • Reduced land surface effects. • Little or no loss of environmental habitat. • No evaporation losses. • Better protection from surface contaminants. • Potential improvements in water quality, streamflow and aquifer levels.	• Limited technical, management and regulatory experience with this storage method. • Possible contamination of existing groundwater by introduced water. • Ownership and/or management of lands over the aquifer may be required similar to Wellhead Protection Areas. • Favorable geology required to limit aquifer leakage.

Water Storage in Washington

Early residents in Washington recognized that the water supply from natural stream flows was limited in the summer months, especially in Eastern Washington. Numerous small dams and reservoirs were built in the late 19th and early 20th centuries to store water from the spring runoff to release water later in the summer to meet the specific needs of irrigation, stock watering and cities.

The first major storage dam project in Washington was the 68-foot-high Nine Mile Dam on the Spokane River, built by the Washington Water Power Company in 1908 for power generation. The first significant irrigation reservoir was the 70-foot-high Conconully Dam and Reservoir, built by the U.S. Reclamation Service in 1910 for the Okanogan Project. In 1914, Seattle built the 215-foot-high Masonry Dam on the Cedar River to provide drinking water for the growing city. In addition to the water supply dams, the U.S. Army Corps of Engineers built several large flood-control dams in the 1940s, including the 350-foot-high Mud Mountain Dam on the White River.

In the ensuing years, dozens of major dam and storage reservoir projects were built for hydropower, irrigation, flood control and municipal supply. Today, there are more than 1,100 dams in Washington, including 80 dams greater than 50 feet in height. A map showing the locations of all dams in the state is shown in Figure 2. A breakdown of the purposes of the larger dams (greater than 50 feet high) is shown in Figure 3.

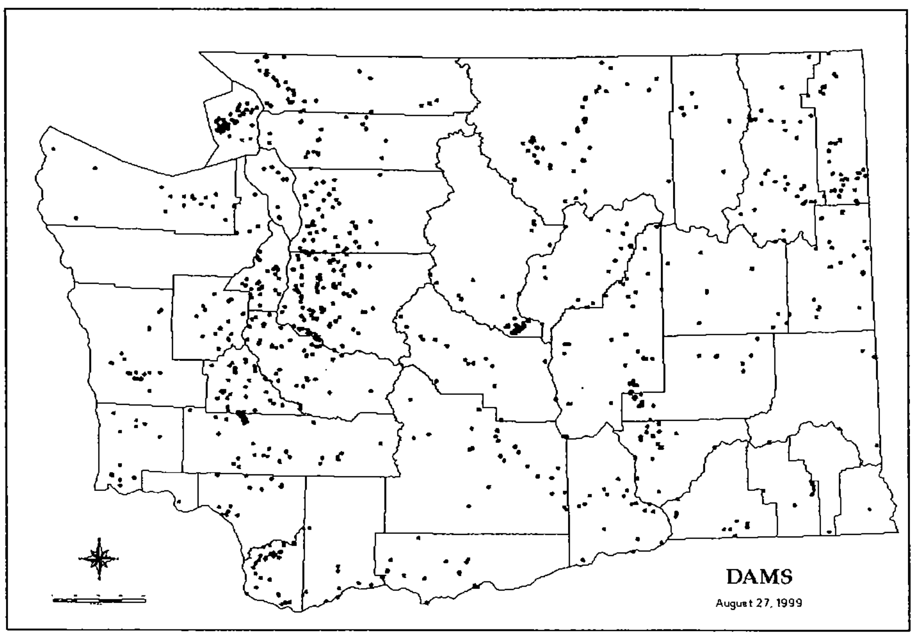
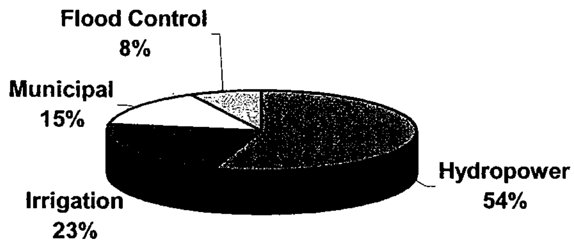


Figure 2: Location of Dams in Washington State

Figure 3.

Primary Purposes of Water Storage Dams Greater than 50 Feet High in Washington



Storage in Surface Reservoirs

Hydropower Reservoirs

The majority of large dams in Washington have been built for hydropower uses. A total of 44 large dams have been built, primarily on major rivers. The projects have been built by a variety of entities, including cities, public utility districts, and private utilities. While these dams store a large quantity of water, their primary purpose is non-consumptive generation of power, with some flood control provided as a secondary benefit. For the most part, these projects do not supply a significant quantity of water for consumptive uses, such as municipal supply or irrigation.

Examples of major dams and reservoirs that are primarily used for hydropower include:
- Ross, Diablo and Gorge dams on the Skagit River, owned by Seattle City Light
- Mossyrock and Mayfield dams on the Cowlitz River, owned by Tacoma Public Utilities
- Upper and Lower Baker dams on the Baker River, owned by Puget Sound Energy
- Nine Mile and Long Lake dams on the Spokane River, owned by Avista Corporation

Irrigation Reservoirs

While numerous irrigation reservoirs have been built in Washington by various individuals and agencies, the primary builder and owner of the largest projects is the U.S. Bureau of Reclamation (USBR). The USBR designed and constructed 12 large dams for storage reservoirs in Washington between 1910 and 1985. The largest of the state dams by far is Grand Coulee Dam, which stands 380 feet high and holds over 9.5 million acre-feet of water. Grand Coulee Dam is a multipurpose facility, used for hydropower, flood control and irrigation. The dam cost $1.85 billion in 1998 dollars to construct between 1935 and 1943 *(World Commission on Dams Case Studies: Grand Coulee Dam and Columbia Basin Project, USA, March 2000).*

This dam is the cornerstone of the Columbia Basin Project, which uses a total of nine dams impounding five major and two minor reservoirs to distribute water to more than 550,000 acres of irrigated farmland in the Columbia Basin. The Columbia Basin dams were built between 1935 and 1962. The overall cost of the Columbia Basin Project (excluding Grand Coulee Dam) was $3.6 billion in 1998 dollars.

Municipal Water Supply Reservoirs

Numerous dams and reservoirs have been built for cities and towns since the early 1900s to meet their water supply and distribution system requirements. Most of the large dams with major reservoirs are located along the west slopes of the Cascade Mountains, serving the large cities in the Puget Sound area. These projects were designed to capture some of the winter and spring runoff from rainfall and snowmelt and hold it until needed in the dry summer and early fall months.

The largest projects include:

- Masonry/Chester Morse Reservoir dams and South Fork Tolt River Dam for the city of Seattle
- Casad Dam/Union River Reservoir for the city of Bremerton
- George Culmback Dam/Spada Lake for Snohomish County and the city of Everett

Many cities and counties also use smaller, off-stream reservoirs for storage and/or flow regulation, such as Seattle's Lake Youngs Reservoir, Everett's Lake Chaplain Reservoir, or the Skagit PUD No.1's Judy Reservoir project. The case study on Judy Reservoir is included in Appendix B. Many of these dams have been altered multiple times to increase storage to meet the needs of a growing population.

Flood Control Reservoirs

Most dams in Washington built to store water for flood control have been relatively small, stormwater-detention-type dams that serve small watersheds. However, the U.S. Army Corps of Engineers has built six large dams in the state solely for flood control. The first large flood control dam, Mill Creek Dam, was constructed in 1942 to reduce flooding in Walla Walla. This dam and reservoir is located off-channel in an adjoining drainage, and stores excess flows from Mill Creek via a diversion channel. The largest single-purpose flood-control dam in Washington is Mud Mountain Dam, a 350-foot-high structure constructed by the Corps in 1948 on the White River.

In addition to these single-purpose reservoirs, the Corps works with owners of hydropower and water supply dams throughout Washington to manage them in the winter to reduce the effects of large floods. The capability to store water for flood control is limited on these projects, because flood control operation (requiring that the reservoir be kept empty before the storm season) conflicts with the primary uses of the reservoir for water supply and/or hydropower.

Aquifer Storage and Recovery

Aquifer storage and recovery (ASR) involves storing water via pumping or infiltration in an underground aquifer and recovering it through wells when needed. This technology has been around for some time and is extensively used in other states, including Oregon, but to date has seen limited use in Washington. One of the first significant ASR projects is the OASIS project in Federal Way, proposed by the Lakehaven Utility District. Planning for this project began in 1989 and would store up to 29,000 acre-feet of water. Another significant ASR project has been proposed by the city of Walla Walla, involving storing water in aquifers that have declined as a result of prior use.

Recent Reservoir Storage Projects

Although construction of new large dams and reservoirs slowed considerably in the latter part of the last century, there have been some notable projects constructed in Washington in the last 15 years. Table 2 provides listings and selected details on several of these projects.

Table 2: Recent Water Storage Projects Constructed in Washington

Project Name	County	River or Stream	Year Built	Dam Height (ft)	Storage (ac-ft)	Const. Cost	Purpose(s)
IRRIGATION							
French Canyon Reservoir	Yakima	N.F. Cowiche Creek	1985	56	670	$7.7 million*	Reregulation
Rosa Wasteway 6 Reregulation Reservoir	Yakima	Offstream	1988	18	65	$863,000	Reregulation
Rosa Wasteway 7 Reregulation Reservoir	Yakima		1991	15	15	$403,000	Reregulation
Wenatchee Heights Reservoir No. 2	Wenatchee	Stemilt Creek	1996	30	80	$241,000	Irrigation Supply
FLOOD CONTROL							
Zintel Canyon Dam	Benton	Zintel Canyon	1992	97	2300	$3.9 million	Flood Control
HYDROPOWER							
Cowlitz Falls Dam	Lewis	Cowlitz River	1993	120	10,000	??	Hydropower
MUNICIPAL SUPPLY							
Indian Creek Reservoir	Pacific	Bear River	1989	74	846	$2.3 million*	Municipal
Judy Reservoir Enlargement	Skagit	Offstream	2000	10 foot raise	1700 added	$9 million	Municipal
OASIS Underground Storage Pilot Project	King	Underground	1992	N/A	29,000 potential	$60-70 million ?	Municipal

* Year 2000 dollars

Policies Related to Storage

This section summarizes policies related to storage. Policies contained in government programs related to land management that may affect siting of new storage projects are also mentioned.

State Policies

Washington statutes contain several general policy statements related to water storage. The few key guiding principles related to storage are described below:

- Long-range development goals of the state include furnishing an adequate supply of water for domestic, industrial, agricultural purposes, municipal, fishery, recreational, and other beneficial uses. (RCW 43.83B.010; RCW 43.99E.010)

- It is in the public interest to encourage the impoundment of excess water in basins where there is water available on a seasonal basis that is in excess of the needs of streams or existing water-rights holders. Both storage and other alternatives should be encouraged. The goal is to strengthen the economy and improve the state's environment. (RCW 90.03.255)

- It is state policy to obtain maximum net benefits and support economically feasible and environmentally sound development of physical facilities for diversion and storage. (RCW 90.03.005)

- Storage that serves multiple purposes is preferred over single-purpose storage (RCW 90.54.020)

- In determining the cost-effectiveness of alternative water sources, full consideration should be given to benefits of storage. (RCW 90.54.180(4))

- Agencies are to help applicants seek a safe and reliable water source. Assistance can include creation of interties, storage, and conservation. (RCW 43.21A.064(5))

Detailed citations of state law related to storage, including agency authorities, planning, water rights, permits, and funding are provided in Appendix C.

Federal Policies

Some federal agencies have policies related to managing water, land and other natural resources that would be applicable to water storage projects. Some of these policies will affect any proposed storage project, while other policies will only affect storage projects proposed on federal lands.

The National Marine Fisheries Service (NMFS) has no formal, written policy concerning water storage. Storage projects are reviewed on a case-by-case basis. In general, the stated NMFS policy is to support activities if benefits for fish outweigh the disadvantages (personal communication, Mike Grady, 2000).

The U.S. Forest Service has a written Aquatic Conservation Strategy. The strategy was developed to restore and maintain the ecological health of watersheds and their related aquatic ecosystems. The strategy applies to federal lands managed by the Forest Service and Bureau of Land Management within the range of Pacific Ocean anadromous fish populations. The strategy does not directly address storage projects on federal lands, but its effect is to identify and prioritize certain land for the purpose of watershed restoration and to ensure that proposed activities on federal lands not interfere with the restoration objectives. A copy of the complete Strategy is in Appendix D.

While neither the U.S. Bureau of Reclamation nor the U.S. Army Corps of Engineers has any formal policies on water storage, both agencies have been responsible for planning, constructing and operating a number of the larger structures in the western U.S. These structures serve mostly irrigation, hydropower and flood-control purposes.

Tribal Policies

Some tribal governments have enacted water laws and adopted rules and programs related to managing water and land within their jurisdictions. Neither of the tribes involved with the Storage Task Force has written policies specifically related to storage. As independent governments, water and land-management policies will vary between different tribes.

Planning Considerations

State law provides several planning processes that directly relate to water storage.

Public water system plans

Public water systems are required to prepare water system plans for review and approval by the Washington Department of Health. All systems are required to prepare an initial plan. Larger systems and systems that are expanding need to prepare updates to these plans every six years.

Water system plans are required to include detailed evaluations of future water demand and to demonstrate adequate availability of water supplies to meet that demand. Water storage is routinely evaluated during development of these plans. Smaller storage units are a routine feature of many public water system plans. Some systems also rely heavily on their basin-level storage sites, and water system plans are often the origin of proposed new storage projects.

Watershed plans (2514)

In 1998, the state Legislature passed the Watershed Management Act to provide a framework for local citizens, interest groups and governmental organizations to collaboratively identify and solve water-related issues in each of the state's 62 Water Resource Inventory Areas (WRIAs). Two-thirds of the WRIAs in this state are currently involved in planning under the Act, and many of the watershed plans called for under the act will be prepared and adopted in the next few years.

One step in this planning process involves an assessment of the watershed, including a description of water supplies, uses and needs. The resulting watershed plan must include strategies for meeting future needs, both in-stream and out-of-stream. Water storage is expected to be a major feature of many of these watershed plans.

Land-use plans

Washington cities and towns have had land-use plans for years. Under the Growth Management Act (GMA), many local governments are required to plan for financing and delivering services needed to meet planned growth, including water supplies. Where growth is projected to occur in areas with limited existing water supplies, water storage can be an important tool for meeting the utility planning requirements.

Though GMA plans are not required in all parts of the state, local land-use plans of one form or another are prepared in all jurisdictions. Local land-use planning, whether done under GMA or outside GMA, could provide an opportunity to evaluate the need and potential for water storage.

Permits for Storage

Regulatory review and approval of water storage facilities usually involve multiple state and federal permits. A summary of some of the major permits and approvals that may be required for a storage project is provided below.

Environmental Review

Water storage projects that require local, state or federal approval require environmental review under the State Environmental Policy Act (SEPA) and/or the federal National Environmental Policy Act (NEPA). Environmental review is not a permit per se, but is intended to ensure that environmental values are considered during decision-making by government agencies. This review involves identifying and evaluating probable effects for all elements of the environment. Many water-storage projects will likely require the preparation of an environmental impact statement (EIS). When a project requires both a state and a federal EIS, the lead agencies can decide to prepare a single document to meet both state and federal requirements.

JARPA Permits

Numerous permits may be required for any water storage projects that involve working in or near state waters. These permits are typically applied for through the Joint Aquatic Resource Permits Application (JARPA). JARPA can be used to apply for the water-related permits shown in Table 3.

Fish and Wildlife Mitigation Policy

The Washington Department of Fish and Wildlife (DFW) has a formal policy related to mitigation that is applicable to proposed water storage projects. The policy is applied by DFW when issuing or commenting on environmental permits. The stated goal of the policy is to achieve no loss of habitat function and value. The hierarchy or continuum of preferred actions is (1) avoiding damage, (2) minimizing damage, (3) repairing damage, (4) reducing damage through long-term maintenance, (5) compensating damage by replacing resources and (6) taking corrective measures over the long-term. It lists the guiding principles for making decisions on appropriate mitigation activities, required elements of mitigation plans and appropriate legal documentation. A complete copy of the policy is in Appendix E.

Table 3: Typical Permits Covered under JARPA Related to Water Storage

Permit	Purpose	Trigger/Activity	Responsible Agency
Hydraulic Project Approval (HPA)	To provide protection for all fish life.	Work that uses, diverts, obstructs, or changes the natural flow or bed of state waters.	Department of Fish and Wildlife, Habitat Program
Water Quality Certification (401)	To ensure that federally permitted activities comply with the federal Clean Water Act, state water quality laws and any other state aquatic protection requirements.	Applying for a federal license or permit for any activity that could cause a discharge of dredge or fill material into water or wetlands, or excavation in water or wetlands.	Department of Ecology, Shorelands & Environmental Assistance Program
Coastal Zone Management Certification (CZM)	To assure compliance with state and Federal Clean Water Act, SEPA, Shoreline Management Act & Energy Facility Site Evaluation Criteria	Conducting projects authorized by the federal agencies and/or applying for certain federal permits or funding.	The federal permitting agency or Ecology Headquarters, Shorelands & Environmental Assistance Program
U.S. Army Corps of Engineers 404 Individual Permits: Discharge of Dredge and Fill Material	To restore and maintain the chemical, physical, and biological integrity of the nation's waters.	Placing a structure, excavating or discharging dredged or fill material in waters of the U.S., including wetlands.	U.S. Army Corps of Engineers
U.S. Army Corps of Engineers Section 10 of the Rivers & Harbors Act, Individual Permit: Work in Navigable Waters	Prohibits the obstruction or alteration of the navigable waters of the U.S. without a permit from the Corps of Engineers.	Placing structures and discharging material in navigable waters of the U.S., including wetlands.	U.S. Army Corps of Engineers
Shoreline Substantial Development Permit	To provide public involvement in the permit process and to foster appropriate uses and protection of the shorelines of the state.	Interfering with normal public use of the water/shorelines of the state, or developing or conducting an activity valued at $2,500 or more on the water or shoreline area.	Local Government (City or County)

State Water Rights/Reservoir Permits

Under Washington Water Code, there are three possible authorizations required for surface-water storage projects.

1. A water right permit or certificate is required to divert or withdraw water to an off-stream reservoir. On-stream reservoirs do not require this authority.

2. A reservoir permit or certificate is required to impound and store water if the reservoir is storing more than 10 acre-feet in volume or if it is 10 or more feet deep at its deepest point.

3. A third permit or certificate that may be necessary is a secondary permit(s) for using reservoir water outside the reservoir.

When practical, the authorizations to divert or withdraw public waters, to store water within a reservoir, and to use stored water outside the reservoir are combined into a single document.

For storing underground water, a water right permit is also required to divert or withdraw water to storage. Under legislation recently passed, the code now allows application for aquifer reservoir permits similar to applying for a surface reservoir permit. The legal need for secondary permit(s) to use reservoir water outside the reservoir is currently under discussion.

Other state laws allow for ground-water storage based upon creating a ground-water management area or sub-area by Ecology, the filing of declarations by a water user claiming to store and withdraw ground water, and confirmation by Ecology. There are several existing rights to store and withdraw ground water established under this process.

There is currently a long wait for processing new water-right applications, resulting in significant uncertainty as to the legal availability of water for storage projects.

Dam Safety Permit

A Dam Safety Construction Permit is required from the Department of Ecology's Dam Safety Office before constructing or modifying any dam or controlling works that can store 10 or more acre-feet of water. This requirement may apply to dams and storage lagoons for: flood control; domestic or irrigation water; domestic, industrial, or agricultural wastes; and mine tailings. Permit processing averages from six to eight weeks, but varies depending on the complexity of the project. Ecology also inspects the construction of all dams to reasonably secure safety of life and property.

Other State Permits

- Department of Natural Resources Forest Practices Permit – A forest practices approval is required of the owner/operator of land and timber before beginning any forest practice, such as harvesting, road construction, etc. Applications are generally processed in five to 30 days (RCW 76.09 and WAC 222).

- Department of Ecology Water Quality Modification – These permits are issued to address turbidity in water during construction, chemical applications in water, or other situations requiring a temporary modification of a water quality standard (RCW 90.48.445 and WAC Chapter 173.201A-110(2)).

Environmental Considerations

When many of the dams and reservoirs were built in Washington state, the environmental effects of these projects were a secondary consideration. Today, many important environmental issues can affect the feasibility and siting of new storage projects. The presence of environmental issues does not automatically preclude the possibility of building a storage project. Some projects may not be "environmentally feasible." For other projects, the presence of significant environmental issues means that additional planning and mitigation will likely be needed, with a concomitant increase in cost and time. Still other water storage projects provide a good opportunity to enhance or restore fish and wildlife habitats.

Environmental considerations for water storage projects will vary by the type of storage (e.g., surface reservoir or aquifer storage) and by the resources that exist at the proposed storage site. Endangered species and the environmental role of flooding are two significant issues that will surface on many storage projects.

Endangered species

The declining status of many salmon species in Washington has resulted in their listing as either endangered or threatened under the federal Endangered Species Act (ESA). The ESA listing could have a significant effect on the state's ability to construct new storage, as well as managing existing storage. There are three major ways in which the ESA may affect existing or new water storage projects.

- First, where a proposed federal action might affect a listed species, the federal agency is required to consult with either the National Marine Fisheries Service (for anadromous fish) or the U.S. Fish and Wildlife Service (for wildlife and non-marine fish) to determine if the action will jeopardize the species. If it does, the action is either prohibited or modified so that jeopardy does not occur.

- Second, to provide protection from ESA sanctions, private landowners, public agencies and others have developed habitat conservation plans (HCPs) that reduce harm to certain listed species while ensuring their long-term protection.

- Third, where actual harm has occurred to a listed species, litigation can be initiated by the federal government or a citizen to enforce the protection requirements of the ESA. For example, an irrigation district in southwest Oregon was forced to remove an irrigation dam to protect a listed fish species.

Endangered species can be a significant challenge for new storage projects. However, if properly designed, storage projects can also provide direct benefits to endangered species.

Environmental Role of Floods

While high flows and flooding can result in significant damage to the human built environment, natural flooding events have shaped many of the features of our watersheds, and they continue to play an important role in sustaining the natural ecosystem functions. A river ecosystem encompasses the river itself, the riparian areas adjacent to it and the substrate below the water. All three are important in providing for healthy fish stocks.

Water temperature, flow in the river and under ground, timing of flow, nutrients, and physical features of the stream channel can affect the ability of the stream to support aquatic life. These features, in turn, are affected and shaped by flooding events. When these events are eliminated, the physical features of the stream can be altered over time and the natural capacity of the stream can be diminished.

Recent advances in the science of river systems have underscored the importance of the natural flow regimen of a river as the template that formed the diversity and abundance of aquatic species. A body of science known as Normative River Concept emphasizes the ecosystem functions of the variability of the natural hydrograph, including the benefits of high spring flows and river floodplain interactions, as well as stable, ample base flows.

Water storage projects that reduce or eliminate natural flooding events in a river system will likely need to address the potential implications to natural functions in the watershed. Analysis and evaluation of these storage projects will likely involve demand curves for each purpose of water needed from the project, including fish.

Operational Considerations

How a water storage project is operated can affect the benefits and consequences of the project.

Using reservoirs for multiple purposes can help spread the benefits (and costs). However, different purposes may need the storage capacity at times that conflict with each other. For example, flood control operation tends to conflict directly with water supply operations, as flood control reservoirs need to be lowered at the time when water supply uses would dictate filling.

Many large hydropower projects have allowed other smaller uses of their water storage reservoirs, under a so-called "good neighbor" policy. However, if these consumptive uses significantly affect power production, the senior and primary uses of the reservoir could assert their right to the water.

Constructing new dams or raising existing dams has public safety implications to downstream residents and property. Raising existing dams will require increased efforts to ensure the safety of these dams. Also, land-use management should be considered below these dams to avoid increasing the risk posed by the dam.

Land-use management is also a consideration for aquifer storage sites. Protecting aquifer storage sites may require actively managing land uses at the storage site to prevent contamination of the stored underground water.

Many reservoirs have a pool of water below the lowest release point on the dam that is typically not used, known as "dead storage." "Dead storage" is used in some existing reservoirs and could be used in other projects. However, the effects to carryover storage, to other uses of the reservoir, and to habitat may make it unfeasible except for emergencies.

Financing of Water Storage

Funding for water storage has come from several places and varies depending on the purpose of storage. In general, federal dollars have paid for the majority of flood control, irrigation and hydropower storage projects in Washington state. State funding, local government or special purpose districts, and water users have funded the remainder.

For hydropower and irrigation uses, funding for storage projects has mostly come from the public. Federal funds from the U.S. Bureau of Reclamation have paid to construct and operate 58 hydropower plants and 348 reservoirs in 17 western states. The Columbia Basin and Yakima projects, the largest water storage projects in the state, were largely built with these funds. The Yakima enhancement program -- in which the U.S. Bureau of Reclamation , irrigation districts, and Ecology are working together to conserve water, rehabilitate and improve district distribution facilities -- is also primarily funded through federal dollars. Funding from the Corps of Engineers paid for other dams, such as Mud Mountain, Howard Hanson, Wynoochee and several dams on the Columbia and Snake Rivers.

State money has also been used to construct some storage projects in Washington. Referendum 27 was a bond issue in 1972 and provided $25 million dollars for agricultural water supply facilities. All funds were spent. Referendum 38, passed in 1980, provided $50 million for agricultural supply/storage/conservation projects. Rules for Referendum 38 were adopted in 1990 with two phases. Irrigation districts could elect to prepare water conservation plans and then receive state funding for a portion of the capital cost. The Drought Preparedness Account from 1989 provided approximately $12-15 million in loans or grants for short-turn-around drought projects. Funds are available only to public bodies such as irrigation districts and Indian tribes.

Local match funding for the public funds has typically come from the irrigation districts.

For municipal projects, Referendum 38 provided $75 million for public water supplies. However, rate revenue and bonds have been used more recently for storage projects. Storage for fish and wildlife has usually been funded as an add-on to storage projects funded for other purposes.

There is currently no single, clear answer on how new storage projects can be funded. State infrastructure studies have shown the need for water supply projects, but existing sources of public funding are currently oversubscribed. Many storage projects will cost more than a single utility could afford. As a result, coalitions of interests may need to be formed to put together the necessary funding.

Typical Costs

It is difficult to provide precise cost information for "typical" storage projects, because the costs can vary significantly depending on the location, siting, engineering requirements, environmental effects and mitigation, difficulty of construction, and purpose(s) of the project.

However, data on recent projects show that the costs can vary from around $200 per acre-foot of storage for raising existing dams to more than $10,000 per acre-foot for new re-regulation projects with small storage capacity. In general, the cost per acre-foot tends to be higher for small reservoirs and much lower for large reservoirs. Also, projects to construct new dams tend to cost more than raising existing dams. Tables 4 and 5 provide some comparative cost data for selected projects in Washington and other states.

Table 4: Construction Costs for Selected New Reservoirs in Washington and Other States

Project Name	On/Off Channel	Total Cost	Dam Height	Storage	Cost/AF	Purpose/Use
In State						
Zintel Canyon Dam	On	$3.9 million	97 ft.	2300 acre-feet	$1,695	Flood Control
Wenatchee Heights #2 Reservoir	Off	$241,600	30 ft	80 acre-feet	$3,020	Irrigation
Rosa Wasteway 6 Reregulation Res.	Off	$863,000	18 ft	65 acre-feet	$13,280	Irrigation Reregulation
Pine Hollow Reservoir	Off (Proposed)	$50.5 million	185 ft.	24,000 acre-feet	$2,145	Irrigation, Fish
Other States						
Ritschard Reservoir (Colorado)	On	$32 million	122 ft.	66,000 acre-feet	$485	Irrigation, Municipal
Westminister Lake (Colorado)	Off	$3.7 million	31 feet	955 acre-feet	$3,860	Municipal
Eastside Reservoir (California)	Off	$2.1 billion	280 feet	800,000 acre-feet	$2,625	Municipal, Irrigation

Table 5: Construction Costs for Selected Dam & Reservoir Enlargements in Washington

Project Name	On/Off Channel	Total Cost	Dam Raise	Storage Increase	Cost/AF Increase	Purpose/Use
Patterson Lake Dam	Off	$100,000	3 feet	500 acre-feet	$200	Irrigation, Recreation
Keechelus Dam *(Cost to rebuild dam and retain storage instead of permanent drawdown)*	On	$31.9 million	N/A	110,000 acre-feet	$290	Irrigation
Cle Elum Dam (Proposed)	On	$16.7 million	3 feet	14,600 acre-feet	$1,140	In-Stream Flow
Wenas Dam (1982)	On	$3.5 million (Yr. 2000 dollars)	35 ft	2,200 acre-feet	$1,590	Irrigation
Judy Reservoir (Under Construction)	Off	$9 million	10 ft.	1,700 acre-feet	$5,294	Municipal

Construction Costs for Aquifer Storage and Recovery Projects

The cost of Aquifer Storage and Recovery (ASR) projects is variable and site specific. A systematic assessment of costs for ASR systems has not been published, and the estimates presented are based on limited research of ASR systems nationwide.

Feasibility and pilot testing programs generally range between $100,000 and $500,000 for systems with existing infrastructure. Published annualized unit costs for developed water using ASR range from $30 to $350 per acre-foot ($92 to $920 per million gallons) for systems that do not require new treatment facilities. Costs are significantly higher for systems that require new treatment facilities or other major infrastructure upgrades.

Alternatives to Storing Water

Water storage is one of several water management tools that can provide additional water to meet identified needs. Since the availability and needs for water vary, the use of storage and other tools will differ across the state. Evaluating these tools and decisions on how current and future water needs will be met are best made using a basin-by-basin approach.

Water conservation programs and reclaimed water can provide additional water in many areas. Conservation programs can free up water currently in use and provide new supplies for a relatively small cost. The opportunities for conservation and the costs will depend on how water is currently used in a given area. Reclaimed water is municipal wastewater effluent that is treated to allow use for irrigation or other non-potable purposes. There are significant volumes of waste water that could be reclaimed and put to use, though the costs of treatment and distribution are a significant issue.

In addition to new storage, conservation and re-use, preserving existing natural storage is an important feature for efficient water management. One of the biggest sources of storage is natural groundwater storage, which helps maintain the base flow in streams in the low-flow summer months. Precipitation falling on impervious surfaces such as roads and roofs runs off quickly, resulting in higher winter flows and less infiltration, which reduce natural storage.

Stormwater storage facilities can retain the runoff from urban areas and release it more slowly, which can prevent flooding and erosion. They can also be designed to infiltrate the runoff back into the ground. Small-scale infiltration features can be built into new urban areas, such as leaving more natural vegetation, small-scale infiltration basins, etc. Enhancing snow retention in agricultural areas may also help infiltration.

All these measures could help improve the natural storage in underground water, which will, in turn help, maintain ground-water levels and stream flows during crucial periods of need.

Conclusions

Importance of Water

1. Water is a vital resource for Washington State. Dependable water supplies of sufficient quantity and quality are essential to the economic and environmental health of the state.

Role of Storage

2. Storage can be an important and useful water supply and environmental management tool. Water storage can:
   - Address the needs of all water users.
   - Provide supplies for economic development and population growth.
   - Be used to restore fisheries and help preserve the biological integrity of our watersheds.
   - Enhance recreational activities and provide protection from destructive floods.

3. Members of the Waster Storage Task Force have differing opinions on the relative importance of storage in meeting future water supply needs:
   - Some members believe it is the only tool that will allow the state to meet its future water supply needs in much of the state. These members note that storage is the only method that will produce large enough quantities to meet the identified needs. They also note that storage to produce new supplies will avoid the need to fight over water rights and ownership of existing supplies.
   - Other members believe it will be an important tool in some basins and not in others, and must be used in conjunction with other water supply and demand management options (e.g., conservation, water transfers, and water reuse). These members note that storage options can be very expensive and controversial, and that future needs may be met by water conservation, re-use and marketing of existing supplies in some areas of the state.

Planning For Storage

4. There are many areas in Washington that have abundant, and some times excessive, water during the wet season that could benefit from further evaluation of storage as a tool to meet current and future water needs.

5. The watershed planning process is a significant and timely opportunity for evaluating water storage as a management strategy to meet water needs.

6. Storage projects which are part of an overall plan or agreement among the federal, state, local and tribal governments regarding water management in a basin, and storage projects that serve multiple purposes are most likely to be successfully sited and funded.

7. Different uses of storage may compete with each other by requiring that water be stored or released at different times of year. Optimizing use of storage for one purpose (releasing water from a reservoir to make room for flood control) can hamper the ability to secure other

storage purposes (saving water in a reservoir for later production of hydropower).

8. Planning for new storage projects should consider how to balance the full range of potential uses for the stored water.

Evaluating Storage Projects

9. Because of the complex economic, technical and environmental issues surrounding storage projects, the feasibility of each project must be determined on a case-by-case basis.

10. The potential benefits and impacts of any particular storage project can only be determined by assessment of that particular project and its watershed.

Environmental Considerations

11. If a storage project is to be designed to benefit fish, not just to minimize harm to fish, the design and operation of the project must take into account the variations in timing and flow that support important habitat and crucial ecological functions.

12. Aquifer storage and recovery (ASR) projects, when properly sited and operated, could result in less harm than surface alternatives.

Funding

13. Funding is essential for developing storage projects. Construction costs can vary significantly, with recent project costs ranging from around $100 to more than $10,000 per acre-foot of stored water. New, large storage projects can cost millions of dollars. Planning, design and permitting can also be a significant portion of the total costs. While some public funding is available for select storage uses, the existing public funding programs are severely over-subscribed and would not cover the full cost of a storage project.

14. Funding will need to come from a variety of sources, including a new source of public funds.

Land Use

15. On-site and local practices to manage storm water (e.g., reducing impervious area and providing infiltration basins) will reduce flooding, improve water quality and benefit the water quantity of a basin by preserving the "natural storage" capacity of the land. Storm water that is recharged to the ground will help sustain aquifers and dependent streams during low-flow periods.

Recommendations

Water supply as a state priority

1. Providing adequate water at the right time for diverse needs of the state including people, fish, and agriculture should be a high priority.

Role of the State

2. State agency responsibilities for water storage should be coordinated by Ecology. This would include: providing technical assistance; ensuring effective participation by state agencies; assisting in bringing state, local, tribal, and federal agencies together; and encouraging timely, regulatory review by state agencies. Ecology's coordinating role applies to major projects and planning, not individual projects such as the approval of domestic water storage tanks or other items typically reviewed by Department of Health in water system plans.

Permits and Laws

3. Without compromising environmental review and public involvement, the state should identify and implement efficiencies, to streamline the permitting process of siting and constructing additional water storage projects, reducing the amount of time and overall cost of these projects.

4. The legislature should evaluate existing state laws related to storage to determine if there are gaps or conflicts that need to be addressed.

Planning for Storage

5. Planning for new water storage projects should consider the full range of storage alternatives, including off-channel storage, underground storage, the enlargement or enhancement of existing storage, and on-channel storage; and of both large and small scale (e.g., small stormwater facilities) options.

6. Planning and design for storage should be considered in the context of how water works within an entire basin or watershed. This includes consideration of the natural variability of stream flow and its interaction with the floodplains and associated ground waters, as well as scientific analysis of the water needs of all life stages of the species of interest present in the basin. Planning for storage should also address how storage will integrate with the water supply and delivery system(s) within an entire basin.

7. Water storage infrastructure needs should be inventoried and assessed through watershed planning processes. The inventory should include all public and private water systems. The inventory should ensure that small drinking water systems and fire safety needs are addressed.

8. Consistent with the Watershed Management Act, and other laws, the state should help local watershed planning groups, local governments, utilities, and other stakeholder groups define:
   - The current and future water supply and demand in their watersheds, including in-stream and off-stream needs;
   - The type of storage projects for that watershed; and
   - Potential storage site locations.

9. The Watershed Management Act manual should be updated to add a section on storage. Topics to include are:
   - Different types of storage;
   - Case studies of successful and unsuccessful projects, including aquifer storage and recovery;
   - Recommended procedures for evaluating storage projects; and
   - Recent advances in the science of how a river system supports the diversity of aquatic species, including the latest information on addressing the types of flows that are necessary to provide for key ecological functions of the river system.

10. Groups planning for water storage should be encouraged to include climate fluctuations as it impacts the availability of water as part of the planning processes.

11. The state Dam Safety Office should advise local governments of the status of dams within their jurisdiction so informed local land use decisions can be made.

12. Ecology should work with federal agencies to develop clearer policies and procedures for use of federal lands for water storage projects.

Funding

13. The state needs to pursue creative methods to facilitate the financing of water storage projects, including consideration of: (1) direct appropriation of federal funds; (2) use of salmon recovery funds (federal and state) to help pay for the fish flows and fish features of storage projects; (3) use of state bonding capacity. In addition, some members of the task force suggested consideration of the use of power revenue resulting from changes in flow augmentation programs on the Columbia River mainstem.

14. The legislature should consider establishing funding sources for the design and construction of water storage projects, in consideration of the following:
   - Priority for funding should be provided to projects identified in adopted watershed plans or to projects that are part of an approved HCP or other intergovernmental agreement.
   - The funding should promote a cost-share contribution from those who would directly benefit from the storage.
   - The funding should, at a minimum, cover the costs of storage benefits that would accrue to fish recovery and enhancement and to other general public purposes.
   - Prioritize projects that address multiple needs for water supply and/or flood control.
   - The funding should emphasize small or medium-scaled projects using off-channel or underground storage, or projects that enlarge existing storage sites.

15. When considering infrastructure needs, the legislature should consider water storage projects.

Types Of Storage

16. State and local governments should improve utilization of natural aquifer recharge where practical, by prioritizing measures that control increased runoff.

Role of Storage

17. All task force members agree that properly designed and sited storage is one of several tools available to meet the water supply needs of the state. However, the members have differing recommendations on whether or not storage should be considered in conjunction with other water management tools.
    - Some members recommend that water storage projects be pursued as the primary water management tool in most of the state. These members say that storage is the only method that will generate the quantities required to meet the water supply needs.
    - Other members recommend that water storage be developed in conjunction with water conservation, water reuse, water transfers and water acquisition. These members say that these other water management techniques can extend the life of existing storage facilities and reduce the size and cost of new storage facilities.

Fish Passage

18. Fish passage should be addressed consistent with current laws when developing new water storage dams or when making major modifications to existing water storage dams. When assessing basin needs for storage infrastructure, watershed planning groups should evaluate the need for providing fish passage through existing or future storage projects, including evaluating the water supply needed to operate the fish passage facilities and funding to build the passage structures.

19. All task force members agree that major modifications to existing storage dams will involve an evaluation of the needs and opportunities to provide for fish passage. However, members have differing recommendations on whether passage should be restored on all existing storage dams when they undergo major modifications.
    - Some members recommend that restoring fish passage to existing dams should be pursued where it is economically feasible to build the passage, where the fish benefits will warrant this additional investment for a modification project, and where there are available water supplies to operate the passage facilities.
    - Other members recommend that fish passage on existing dams should, in most cases, be restored as a basic requirement for major modification projects.

APPENDIX B

AQUIFER STORAGE AND RECOVERY REPORT TO LEGISLATURE (2001)

Aquifer Storage and Recovery

Definition | New Rule | Benefits | Application Process | Water Quality Issues | Current Projects | Links | Contacts

Chapter 173-157 WAC 1/15/2003
ASR Concise Explanatory Statement

Definition ▲

Aquifer Storage and Recovery (ASR) involves injecting water into an aquifer through wells or by surface spreading and infiltration and then pumping it out when needed. The aquifer essentially functions as a water bank. Deposits are made in times of surplus, typically during the rainy season, and withdrawals occur when available water falls short of demand.

New Aquifer Storage and Recovery Rule ▲

Background

In the 2000 session, the Washington State Legislature passed Engrossed Second Substitute House Bill 2867, which expanded the definition of "reservoir" in RCW 90.03.370 ("Reservoir permits...") to include, "any naturally occurring underground geological formation where water is collected and stored for subsequent use as part of an underground artificial storage and recovery project".

This legislation allows to Ecology to issue reservoir permits to authorize ASR projects. Previously, reservoir permits were only for surface water impoundment projects.

The rule, *Chapter 173-157 WAC - Underground Artificial Storage and Recovery,* establishes standards for review of ASR proposals and mitigation of any adverse impacts in the following areas:

- Aquifer vulnerability and hydraulic continuity
- Potential impairment of existing water rights
- Geotechnical impacts and aquifer boundaries and characteristics
- Chemical compatibility of surface and ground waters
- Recharge and recovery treatment requirements
- System operation
- Water rights and ownership of water stored for recovery
- Environmental impacts

ASR Benefits ▲

Some recognized benefits of Aquifer Storage and Recovery are:

- Substantial amounts of water can be stored deep underground. This may reduce the need to construct large and expensive surface reservoirs.
- ASR systems are considered to be more environmentally friendly than surface reservoirs. They also offer more protection from tampering.
- ASR may restore and expand the function of an aquifer that has experienced long-term declines in water levels due to heavy pumping necessary to meet growing urban and agricultural water needs.

ASR Application Process ▲

In the 2002 legislative session, Engrossed House Bill 2993 simplified the application process for an ASR project by specifying that Ecology "may accept for processing a single application form covering both a proposed reservoir and a proposed secondary permit or permits for use of water from that reservoir."

Following are the basic steps involved in permitting an ASR project:

1. Prior to applying, assess potential issues and impacts to the hydrogeologic system and the environment. If the general setting and conditions cannot be described in sufficient detail for the application, then a more detailed feasibility study must be performed. The feasibility study should reduce uncertainty with respect to project issues and impacts, as well as better quantify the available storage within the aquifer.

2. Schedule a pre-application meeting with Ecology to discuss the project plan and likely requirements for monitoring and mitigation.

3. Submit an application for an ASR project that contains at a minimum:

    a. Water rights for the source waters for the proposed ASR project.
    b. A general description of the physical design of the hydrogeologic system prepared by an engineer or geologist registered in the state of Washington.
    c. A general description of the operational design of the hydrogeologic system prepared by an engineer or geologist registered in the state of Washington.
    d. A project plan.
    e. A data monitoring plan.
    f. An environmental assessment and analysis of any potential adverse conditions or potential impacts to the surrounding environment, limited to storage and subsequent use of stored water, that might result from the project.

Water Quality Issues ▲

Water to be stored in an aquifer as part of an ASR project must meet water quality standards for ground waters of the state of Washington (Ch. 173-200 WAC). Additionally, injection wells for an ASR project must be registered with Ecology in accordance with the provisions of Chapter 90.48 RCW (Water Pollution Control Act) and Chapter 173-218 WAC (Underground Injection Control Program). For more information on the Underground Injection Control program, please see the UIC Website.

Current Projects in Washington

- City of Yakima (1305 KB PDF)
- Lakehaven Utility District (Federal Way) (357 KB PDF)
- Cities of Kennewick & Richland
- Seattle Public Utilities
- City of Walla Walla
- Summary of Projects (Appendix to ASR 2001 Report to the Legislature) (133 KB PDF)

Links

- Artificial Storage and Recovery of Ground Water - 2001 Report to the Legislature
- Appendix to ASR 2001 Report to the Legislature (Summary of Projects) (133 KB PDF)
- ASR Forum Website (ASR Systems, Florida) - A lot of great information on ASR - includes an interactive forum.
- ASR Animation (ASR Systems, Florida) - See how ASR works! (Flash Animation)
- Washington Water Storage Task Force - Read about other water storage issues in Washington

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Ecology Home > Water Resources Home > Aquifer Storage and Recovery

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WASHINGTON STATE
DEPARTMENT OF
ECOLOGY

2001 Report to the Legislature

Artificial Storage and Recovery of Ground Water

Progress Report

December 2001

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WASHINGTON STATE
DEPARTMENT OF
ECOLOGY

2001 Report to the Legislature Artificial Storage and Recovery of Ground Water

Progress Report

by
Doug McChesney
Water Resources Program

Olympia, Washington 98504-7775

December 2001

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Introduction

During its 2000 session, the Washington State Legislature extended the Department of Ecology's authority to issue reservoir permits under the state surface water code to cover projects designed to store water in underground geological formations for future recovery and use. Previously, Ecology only had authority to issue permits for typical surface water reservoirs.

The measure, Engrossed Second Substitute House Bill 2867, E2SHB-2867 (see **Appendix A** for full bill text), defines these types of water storage projects as "artificial storage and recovery", or "aquifer storage and recovery" (ASR) projects as they are commonly called. Under E2SHB-2867, Ecology is required to provide a report to the Legislature by December 31, 2001, outlining its standards for review and mitigation and the status of any applications that have been filed for such projects. This report is submitted in fulfillment of that statutory requirement.

Background

Aquifer storage and recovery projects have been legally possible in the state of Washington since the first days of the state ground water code, Ch. 90.44 RCW, which was enacted in 1945. Early ASR projects came about more by accident than by design, particularly when irrigation districts realized that they were, in effect, recharging water table aquifers through canal leakage. The districts recognized the value of the stored water and sought ways to access that water.

Groundwater management sub-areas

The process developed, and outlined in RCW 90.44.130, allows Ecology to control withdrawals of ground water through the creation of ground water management sub-areas. Ground water management sub-areas, designed for distinct bodies of ground water, can be created either by the agency directly or by petition from local entities.

Prior to the formal designation of a sub-area, Ecology is required to publish notice of its intention and make findings of fact on the designation and any objections.

Within 90 days after a ground water management sub-area is designated, anyone claiming ownership of artificially-stored ground waters must file a declaration, including providing evidence that no water withdrawn is public ground water. If necessary, a claimant may apply for an extension after 90 days. Claimants to artificially-stored ground water subsequent to designation can file similar declarations within three years and, if necessary, apply for extensions of up to two years. Those withdrawing artificially-stored ground water must file similar declarations within 90 days following the earliest withdrawal.

Because the process for declaring ground water management sub-areas was relatively cumbersome and not well suited to meet their needs, ASR proponents approached the 2000 Legislature to propose an alternative process. The new process was created by E2SHB-2867.

The New Process

The process created by the new ASR legislation expands the definition of "reservoir" to include "any naturally occurring underground geological formation where water is collected and stored for subsequent use as part of an underground artificial storage and recovery project." A person wishing to use any water stored in a reservoir must file an application for a secondary permit and provide evidence that an agreement exists with the owners of the reservoir to secure enough water for the secondary permit. Ecology can now issue permits for the storage of water in "natural underground formations" by means of injection, surface spreading and infiltration, or other Ecology-approved methods, as part of an ASR project.

A proposed ASR project would have to meet standards for review and mitigation established by Ecology rule. Those elements to be addressed include:

- Aquifer vulnerability and hydraulic continuity.
- Potential impairment of existing water rights.
- Geotechnical impacts and aquifer boundaries and characteristics.
- Chemical compatibility of surface and ground waters.
- Recharge and recovery treatment requirements.
- System operation.
- Water rights and ownership of water stored for recovery.
- Environmental impacts.

Analysis of each proposed ASR project and geological formation must be conducted through studies initiated by the applicant. The studies will then be reviewed by Ecology. Certain types of projects are exempted from the new law, including operational and seepage losses from irrigation projects, irrigation return flows, water artificially stored as part of irrigation district projects, reclaimed water, or artificially stored water that may be claimed when a groundwater sub-area is established. Existing law governing the issuance of permits to appropriate or withdraw waters remains unchanged.

IMPLEMENTATION OF THE LEGISLATION

Shortly after the legislation took effect, Ecology convened a technical advisory group to determine how best to implement the new legislation. The group included membership from a broad spectrum of interests such as water utilities, local governments, consultants, academics, and state, local, and tribal agencies.

Between July 2000 and January 2001, the advisory group held six meetings. Topics included:

- Background information on the history of artificial storage of ground water in Washington.
- General Washington water law.
- The water-right permitting process.
- Specific legal issues pertaining to ASR projects.

Committee members working on various ASR projects also presented information about their particular projects, which range in size from small projects intended to serve the needs of a single business to large ones that could potentially constitute a major source of water for one or more regional water suppliers.

The advisory committee had completed a draft of the regulation, which was being circulated for review and comment in January 2001, just as Washington entered the state's second-worst drought in recorded history. Therefore, work on the rule was suspended so Ecology staff could work on drought-related issues. The 2001 drought declaration expired on December 31, 2001, so Ecology is resuming work on the ASR regulation.

Framework

In considering the standards to be met by ASR projects, the advisory group agreed that four different aspects should be analyzed prior to permitting:

- **Hydrogeologic** — how water will be stored underground in a reservoir and be available for later recovery and how that operation would affect the area where the recharge and storage will be developed.
- **Operational** — how the project will be operated and over what time cycle.
- **Environmental** — potential effects a proposed project might have on environmental conditions in the vicinity.
- **Legal** — how other water right holders and water users might be affected by a specific project.

The **hydrogeologic analysis** is the primary analysis to be conducted in conjunction with a proposed ASR project. It would, at least initially, include the development of a conceptual hydrogeologic model that identifies the general geological and hydrogeological conditions in the area where the project is proposed. This would include identifying such features as the geologic materials and their thicknesses, structural information such as faults, fractures, or synclines, and other relevant information that would help to describe the general geologic setting in the vicinity of the project. General ground water information should be part of this analysis as well, including such elements as the water bearing units and their hydraulic properties, the general ground water flow system, and any ground water boundaries. The size of a proposed ASR project will have a bearing on the level of detail needed and the amount of investigation required to ascertain its feasibility. Larger and more complex projects may well require considerably more study, including the development of sophisticated computer models as part of the analysis.

The **operational analysis** would describe how the project, once completed, would function. This analysis would include the major elements of the project operation such as the means of recharge (e.g. injection well or spreading basin), the location, number, and capacity of proposed recharge facilities, the source water quality and the means of treatment and disinfection of the source and recovered waters, the timing of both the recharge operations and the use of the stored water, and the rates of recharge and recovery.

The **environmental analysis** would describe probable and potential environmental effects that might result from the ASR project. Possible effects identified in the conceptual model would be considered and assessed, including changes to local water bodies such as wetlands and springs, changes to water levels and water quality in nearby wells, changes in slope stability, and possible subsidence or ground heave. Some of this analysis could be conducted through compliance with the State Environmental Policy Act (SEPA) as part of completing an environmental checklist or preparing an environmental impact statement. The size of the project will have a bearing on the level of review necessary under SEPA.

The **legal analysis** would identify and assess the significance of any potential legal issues associated with a proposed project. This would include identification of any wells completed in the aquifer and water rights connected with them. It would also address any changes necessary to the ASR proponent's water rights to cover the project, including changes to water rights for the source waters, and any legal issues associated with the proposed recharge area, in terms of land use activities, land ownership, and possible adverse environmental effects.

Monitoring plan

A key component of the framework outlined above is the implementation of an appropriately-designed and scaled monitoring plan. A well-designed plan should identify any elements that need additional analysis. The design of a monitoring plan needs to be carefully tailored for each specific project to ensure the appropriate factors are evaluated. The monitoring plan should also provide an early-warning mechanism to detect adverse impacts to the physical, chemical, or biological environments that were not predicted by the conceptual model. The advisory group even discussed making the results of the monitoring plan available to the public as a way to demonstrate compliance with the applicable regulations and reduce concerns about project effects.

Phased approach

Central to the framework identified above is the notion of a phased approach to the necessary investigations, moving from the general to the specific as needed. As shown in **Appendix B**, the scale and scope of potential ASR projects varies greatly. While some are sufficiently large and complex enough to warrant thorough investigation from the start, similar expectations for a smaller project might render it infeasible. Therefore, advisory group members agreed that some form of phased approach made the most sense for all projects. A proponent of a project could conduct preliminary studies and, based on the results of those studies, work with Ecology to determine the need for more detailed investigations. This would also allow the proponent to then make an informed decision about the likely viability of the project.

A phased approach will also help identify possible problems before they pose a threat to the project, other parties, or the environment. Even the most sophisticated analytical techniques can still fail to identify or predict potential problems. The phased approach methodically expands the need for investigations if any problems are found. Finally, because the largest proposed ASR projects will take a long time to complete, this approach will allow necessary investigations to be conducted over time, rather than placing an unmanageable burden on proponents at the start.

ISSUES IDENTIFIED

Changes of purpose of use

Most ASR projects already are operating under one or more water rights, so new water rights are usually not an issue. However, the question arose about whether storage needed to be added as a new purpose of use for the source waters if it was not part of the original water right. This could have posed a serious difficulty since it would have required changes to existing rights. If those rights were inchoate surface water rights, as was the case with some of the proposed projects, adding storage as a purpose of use would not be allowed under current state law (RCW 90.03.380).

The Attorney General's office subsequently advised Ecology that, in itself, storage is not a purpose of use of water. Rather it is merely a means to provide water for the true purposes of use identified in the secondary permit. Therefore, in applying for a reservoir permit under RCW 90.03.370, there would be no need to change the purpose of use of the water to add storage.

Preliminary vs. temporary permits

ASR projects usually require a significant amount of testing to determine their feasibility. Generally, this can be accomplished over a relatively short period of time for smaller projects but larger projects may require years before the full operational capacity of the project can be completely evaluated. Ecology normally authorizes the necessary drilling and testing that needs to take place to determine the feasibility of a new water project through the issuance of a preliminary permit. A preliminary permit requires the applicant to make "such surveys, investigations, studies, and progress reports as the department deems necessary."

The difficulty arises because a preliminary permit is normally issued for a period of three years or less, and can only be extended to a maximum of five years and then only with the approval of the governor. Failure to comply with the conditions of the preliminary permit and the application upon which it is based results in the automatic cancellation of the application. Given the longer time frames necessary to evaluate the viability of some ASR projects, the relatively short duration of a preliminary permit really is an inappropriate and inadequate tool for authorizing the initial investigations.

Presently, the interim solution is to allow initial testing and evaluation of proposed projects to be undertaken under temporary permits, as was done for the city of Seattle's Highline well field. However, the use of temporary permits is only appropriate for projects where the water rights to the source waters are secured and available.

Single line for new applications and reservoir permits

Applications for ASR projects, which require reservoir and secondary permits, must go into the same line as applications for new water right permits. This is probably a vestige of the early days of the water code, when new rights were needed for virtually all new water projects, including storage projects. Applications for new permits must be investigated to answer questions about use and availability of water and effects on other rights and the public interest, often a time-consuming process. In most cases, ASR projects have already secured the necessary water rights for their source waters and simply need to have the storage and recovery elements of the projects evaluated through the permitting process. Some projects could be moved forward in the permitting line if they met the criteria identified in Ch. 173-152 WAC, the *Hillis* rule, but many projects will not meet those criteria. The obvious solution would be the creation of a third line for such ASR projects.

Introduction of disinfection byproducts

Most of the ASR projects proposed thus far are for public water systems and would use treated drinking water as their source waters. However, some of the byproducts of disinfection exceed the state ground water quality standards, Ch. 173-200 WAC. Chlorine, which is the standard method of drinking water disinfection, can react with organic materials that occur in ground water to produce carcinogenic chemicals. While any long-term health and environmental effects from the introduction of those byproducts are extremely unlikely, their removal would be quite costly. Nonetheless, their introduction into the ground water system runs contrary to the antidegradation policy of the ground water quality standards.

Some of the options that were considered to address this problem included the use of alternative points of compliance for determining compliance with ground water standards, possible alteration of the standards to allow any disinfection byproducts to only meet Maximum Contaminant Levels, or the application of the "overriding consideration of the public interest" and "all known, available, and reasonable methods of prevention, control, and treatment" provisions of the water quality standards. The technical advisory group has yet to agree on the most appropriate option to pursue. Fortunately, public water systems are beginning to make the transition to different methods of disinfection, so the problem will gradually cease to exist.

The natural discharge of stored waters

Some advisory group members expressed interest in using ASR projects to augment late-season streamflows by allowing stored water to naturally discharge to a stream, rather than actually withdrawing the water for that purpose. Currently, none of the projects under consideration in Washington would be for this purpose.

Projects of this type are normally referred to as "artificial recharge" projects and are specifically authorized in several western states. However, Washington law presently makes no provisions for such projects. Advisory group members differed regarding whether such projects would, or should, be possible under the new statute. At this point, the issue is undecided, although the prevalent view is that if the Legislature would like to endorse such projects, some change to the statute should probably be considered.

Priority dates

State-issued water rights are assigned a priority date when the application is filed. Applications for ASR permits can only be filed after the effective date of E2SHB-2867. Thus, permits for ASR projects would be junior to most other water rights. In some instances, ASR projects would be junior to established instream flows. There is concern that an ASR project subject to an established instream flow could not operate when flows were not being met. This could, conceivably, prevent the use of the project at a time when it would be most valuable. This potential exists despite the strong chance that the rights for the source waters for ASR projects may be senior to those established instream flows. Advisory group members were uncertain about the likelihood of subjecting ASR projects to instream flows, but the issue remains unresolved.

CONCLUSIONS

ASR has been demonstrated to be a successful way of augmenting water supplies in areas where it is technically and economically feasible. As such, ASR can help address future water supply needs in Washington. ASR projects can vary significantly in terms of size and purpose. The key to making ASR successful in Washington is to provide a program for authorizing ASR projects that provides the necessary flexibility to accommodate the different types of projects while simultaneously assuring the health and safety of the public and the state's environment are adequately protected.

As the technical advisory group discovered, there are several legal and technical obstacles that need to be resolved before the potential of ASR projects will fully be realized in Washington State. Nonetheless, work on possible ASR projects needs to continue, particularly as Washington confronts the dilemma of how to accommodate the future water needs of its population and industry.

FOR MORE INFORMATION

If you have questions or would like further information about aquifer storage and recovery in Washington, please contact Doug McChesney at (360) 407-6647 (e-mail: mcc461@ecy.wa.gov).

APPENDIX A

ENGROSSED SECOND SUBSTITUTE HOUSE BILL 2867

CERTIFICATION OF ENROLLMENT

ENGROSSED SECOND SUBSTITUTE HOUSE BILL 2867

Chapter 98, Laws of 2000

56th Legislature
2000 Regular Session

UNDERGROUND WATER STORAGE

EFFECTIVE DATE: 6/8/00

Passed by the House March 6, 2000
Yeas 98 Nays 0

CLYDE BALLARD
Speaker of the House of Representatives

~~FRANK CHOPP~~
Speaker of the House of Representatives

Passed by the Senate March 1, 2000
Yeas 46 Nays 0

BRAD OWEN
President of the Senate

Approved March 24, 2000

GARY LOCKE
Governor of the State of Washington

CERTIFICATE

We, Timothy A. Martin and Cynthia Zehnder, Co-Chief Clerks of the House of Representatives of the State of Washington, do hereby certify that the attached is **ENGROSSED SECOND SUBSTITUTE HOUSE BILL 2867** as passed by the House of Representatives and the Senate on the dates hereon set forth.

CYNTHIA ZEHNDER
Chief Clerk

~~TIMOTHY A. MARTIN~~
Chief Clerk

FILED

March 24, 2000 - 2:49 p.m.

Secretary of State
State of Washington

ENGROSSED SECOND SUBSTITUTE HOUSE BILL 2867

Passed Legislature - 2000 Regular Session

AS AMENDED BY THE SENATE

State of Washington **56th Legislature** **2000 Regular Session**

By House Committee on Agriculture & Ecology (originally sponsored by Representatives Linville, G. Chandler, Miloscia, Mitchell, Koster and Cooper)

Read first time 02/07/2000. Referred to Committee on .

AN ACT Relating to underground water storage; amending RCW 90.44.035 and 90.03.370; and adding a new section to chapter 90.44 RCW.

BE IT ENACTED BY THE LEGISLATURE OF THE STATE OF WASHINGTON:

NEW SECTION. **Sec. 1.** A new section is added to chapter 90.44 RCW to read as follows:

The legislature recognizes the importance of sound water management. In an effort to promote new and innovative methods of water storage, the legislature authorizes the department of ecology to issue reservoir permits that enable an entity to artificially store and recover water in any underground geological formation, which qualifies as a reservoir under RCW 90.03.370.

Sec. 2. RCW 90.44.035 and 1987 c 109 s 107 are each amended to read as follows:

For purposes of this chapter:

(1) "Department" means the department of ecology;

(2) "Director" means the director of ecology;

(3) "Ground waters" means all waters that exist beneath the land surface or beneath the bed of any stream, lake or reservoir, or other body of surface water within the boundaries of this state, whatever may be the geological formation or structure in which such water stands or flows, percolates or otherwise moves. There is a recognized distinction between natural ground water and artificially stored ground water;

(4) "Natural ground water" means water that exists in underground storage owing wholly to natural processes; ((~~and~~))

(5) "Artificially stored ground water" means water that is made available in underground storage artificially, either intentionally, or incidentally to irrigation and that otherwise would have been dissipated by natural ((~~waste~~)) processes; and

(6) "Underground artificial storage and recovery project" means any project in which it is intended to artificially store water in the ground through injection, surface spreading and infiltration, or other department-approved method, and to make subsequent use of the stored water. However, (a) this subsection does not apply to irrigation return flow, or to operational and seepage losses that occur during the irrigation of land, or to water that is artificially stored due to the construction, operation, or maintenance of an irrigation district project, or to projects involving water reclaimed in accordance with chapter 90.46 RCW; and (b) RCW 90.44.130 applies to those instances of claimed artificial recharge occurring due to the construction, operation, or maintenance of an irrigation district project or operational and seepage losses that occur during the irrigation of land, as well as other forms of claimed artificial recharge already existing at the time a ground water subarea is established.

Sec. 3. RCW 90.03.370 and 1987 c 109 s 93 are each amended to read as follows:

(1) All applications for reservoir permits shall be subject to the provisions of RCW 90.03.250 through 90.03.320. But the party or parties proposing to apply to a beneficial use the water stored in any such reservoir shall also file an application for a permit, to be known as the secondary permit, which shall be in compliance with the provisions of RCW 90.03.250 through 90.03.320. Such secondary application shall refer to such reservoir as its source of water

supply and shall show documentary evidence that an agreement has been entered into with the owners of the reservoir for a permanent and sufficient interest in said reservoir to impound enough water for the purposes set forth in said application. When the beneficial use has been completed and perfected under the secondary permit, the department shall take the proof of the water users under such permit and the final certificate of appropriation shall refer to both the ditch and works described in the secondary permit and the reservoir described in the primary permit.

<u>(2)(a) For the purposes of this section, "reservoir" includes, in addition to any surface reservoir, any naturally occurring underground geological formation where water is collected and stored for subsequent use as part of an underground artificial storage and recovery project. To qualify for issuance of a reservoir permit an underground geological formation must meet standards for review and mitigation of adverse impacts identified, for the following issues:</u>

<u>(i) Aquifer vulnerability and hydraulic continuity;</u>

<u>(ii) Potential impairment of existing water rights;</u>

<u>(iii) Geotechnical impacts and aquifer boundaries and characteristics;</u>

<u>(iv) Chemical compatibility of surface waters and ground water;</u>

<u>(v) Recharge and recovery treatment requirements;</u>

<u>(vi) System operation;</u>

<u>(vii) Water rights and ownership of water stored for recovery; and</u>

<u>(viii) Environmental impacts.</u>

<u>(b) Standards for review and standards for mitigation of adverse impacts for an underground artificial storage and recovery project shall be established by the department by rule. Notwithstanding the provisions of RCW 90.03.250 through 90.03.320, analysis of each underground artificial storage and recovery project and each underground geological formation for which an applicant seeks the status of a reservoir shall be through applicant-initiated studies reviewed by the department.</u>

<u>(3) For the purposes of this section, "underground artificial storage and recovery project" means any project in which it is intended to artificially store water in the ground through injection, surface spreading and infiltration, or other department-approved method, and to make subsequent use of the stored water. However, (a)</u>

this subsection does not apply to irrigation return flow, or to operational and seepage losses that occur during the irrigation of land, or to water that is artificially stored due to the construction, operation, or maintenance of an irrigation district project, or to projects involving water reclaimed in accordance with chapter 90.46 RCW; and (b) RCW 90.44.130 applies to those instances of claimed artificial recharge occurring due to the construction, operation, or maintenance of an irrigation district project or operational and seepage losses that occur during the irrigation of land, as well as other forms of claimed artificial recharge already existing at the time a ground water subarea is established.

(4) Nothing in this act changes the requirements of existing law governing issuance of permits to appropriate or withdraw the waters of the state.

(5) The department shall report to the legislature by December 31, 2001, on the standards for review and standards for mitigation developed under subsection (3) of this section and on the status of any applications that have been filed with the department for underground artificial storage and recovery projects by that date.

Passed the House March 6, 2000.
Passed the Senate March 1, 2000.
Approved by the Governor March 24, 2000.
Filed in Office of Secretary of State March 24, 2000.

Appendix B
Summary of major ASR projects in Washington

Compiled from submitted material by Doug McChesney.

Appendix B: Summary of major ASR projects in Washington

Cities of Kennewick and Richland

Together, the cities of Kennewick and Richland are evaluating the feasibility of ASR as part of an overall water resources plan to meet future water supply needs. Part of the plan would use Richland's existing Willowbrook well, which has mostly been used as an emergency backup when the city's primary water sources have experienced elevated temperatures.

Groundwater from the Willowbrook well contains hydrogen sulfide and methane that cause taste and odor problems. Due to these water quality conditions, Kennewick and Richland would like to determine whether ASR can improve well water quality and allow the cities to use the well more often without customer complaints.

Under the ASR proposal, Columbia River water from the cities' treatment plants would be recharged into the Wanapum Basalt aquifer using the Willowbrook well. The length of the storage period as well as the percentage of recharged water recovered would vary, depending on the hydraulic properties of the aquifer, the physical and chemical changes to the water during storage, and the length of demand.

The overall objective would be to design a reliable system to maximize the recovery of recharge water while providing consistent water quality to the municipalities' customers. Development of the Richland ASR appears to be feasible, based on an evaluation of new and existing information, provided the Willowbrook well:

- Is completed in a moderately transmissive portion of a basalt aquifer that cannot impact surface water.
- Meets state well construction standards and is equipped with a pump that can be easily modified for ASR operations.
- Is connected with the city of Richland distribution system so recharge water can be easily conveyed to the well.
- Does not seriously affect the few major users of groundwater from the basalt aquifer in the vicinity of the well.

However, there are also some factors that need to be addressed before the Richland ASR can move forward. These include:

- Groundwater temperatures need to be reduced sufficiently.
- Detectable levels of methane and hydrogen sulfide need to be low enough.
- The presence of disinfection by-products in the recharge water, sometimes at levels higher than current state water quality (anti-degradation) standards, needs to be addressed.

Permitting status — The feasibility study was just completed and the cities have yet to submit any applications for reservoir and secondary permits.

Lakehaven Utility District

The Lakehaven Utility District, located in Federal Way, has one operational ASR well that has been used as a pilot since 1991. The district is planning additional ASR wells as part of their Optimization of Aquifer Storage for Increase Supply (OASIS) project. The Federal Way area, like nearly all Western Washington, receives most of its precipitation between October and April when water demand is relatively low. The OASIS project is intended to operate seasonally, storing excess winter water from either ground or surface water sources and making it available between May and September when customer demand is at its peak and regional precipitation at its lowest.

Currently, the district's source water comes from the Redondo-Milton Channel aquifer which lies above the Mirror Lake storage aquifer. The shallower aquifer provides natural recharge to the storage aquifer and is more susceptible to variations in seasonal precipitation. During wet years, excess water from the channel aquifer recharges the storage aquifer. In drier years, the channel aquifer is supplemented with water from the Mirror Lake aquifer.

In the future, excess winter surface water will be available as recharge to the storage aquifer, allowing the storage aquifer to supplement high and higher summer demands both locally and regionally. The source of the winter recharge water would come primarily from the Green and Cedar rivers.

The Mirror Lake aquifer has an estimated usable storage volume of 29,000 acre-feet. It consists primarily of coarse sand and gravels with aquitards above and below the aquifer. Wells have been screened from approximately 100 feet above sea level to about 200 below sea level with an average screen length of around 60 feet. The raw water quality meets both primary and secondary drinking-water standards.

There are currently three wells in the storage aquifer. Two wells provide recovery while the third is a duel-purpose recharge and production well. In the future, as many as 27 wells are contemplated. Past operational tests, using groundwater as the source water, have not included pre- or post-treatment. However, if surface water is used, it is expected that pre- and post-treatment will be required.

Permitting status — No action has yet been taken on the district's application. Lakehaven Utility District applied to Ecology for reservoir and secondary permits shortly after E2SHB-2867 became law, primarily to secure a place in the permitting line. The district continues testing for the project.

Small-scale ASR in Redmond

An electronics firm in the city of Redmond is constructing a data facility designed to withstand and remain in operation after a major earthquake. As part of its requirements, the facility will need a reliable source of emergency cooling water at a maximum sustained rate of 175 gallons per minute until its normal connection with the city of Redmond can be re-established. The maximum design stored volume for a 50-day supply is approximately 10 million gallons.

The firm is evaluating the feasibility of using a small-scale ASR system to provide a reliable supply of emergency cooling water for the facility. ASR is being considered for the following reasons:

- Well technology has been shown to be reliable in large-magnitude earthquakes, particularly if a facility's power and piping are designed for the event.
- The likelihood of obtaining a new groundwater right in the known aquifers is low due to the over-appropriation and potential surface water-ground water interconnection issues in the area.
- The availability of an existing water right for purchase is uncertain and appears to be unlikely.

Even though ASR is envisioned as primarily for emergency supply, an annual operational cycle is proposed for the system to provide the following benefits:

- Annual exercise of the system to ensure operational reliability.
- Use of the ASR system for facility cooling water during peak usage times in the summer to provide relief to the regional water supply.
- Replenishment of the stored water "bubble" after migration during storage periods.

The key feasibility factors to be addressed in 2002 include obtaining a commitment on the part of water purveyors to provide source water for the facility and for ASR injection, determining the permitting requirements for the project, and drilling a test well to verify the presence of a separate deeper aquifer that can accommodate the desired ASR system.

Permitting status — As the summary indicates, this project is still in its early stages of development. Project proponents have not submitted any applications to Ecology at this time.

Seattle Public Utilities

During the 1980s, the Seattle Water Department, now called Seattle Public Utilities, developed and put the Highline well field in service. The well field consists of three production wells capable of delivering a total of 10 million gallons per day. The well field has two basic uses:

- A peaking source that could be started in July and run for up to four months.
- An emergency supply.

In the early 1990s, Seattle Public Utilities received a grant from the U.S. Bureau of Reclamation to study artificial recharge as a means to enhance its Highline well field productivity. Artificial recharge of the aquifer with treated drinking water from the utility's Cedar River source was found to be feasible.

Two production wells are configured so water can be dropped by gravity down the space between the well casing and the pump column and out through the well screen into the aquifer. The ASR study found that artificial recharge in the Highline well field will not increase production capacity significantly above the current 10 million gallons per day. However, its use following heavy pumping of the well field will hasten the return of the aquifer to pre-pumping conditions. Seattle utility operators currently favor the use of its Cedar and South Fork Tolt surface water sources, so the Highline well field has been used only sparingly in recent years and augmentation of the natural recharge to the aquifer has not been needed. Even so, it is considered a viable technique that should be "on call" for future well field operations.

Permitting status: Seattle has operated its Highline well field ASR project for several years under a series of temporary permits issued by Ecology. In 2001, Ecology sought to update the permitting status of the project but was advised by counsel to ensure that Seattle complied with the terms and conditions of the new legislation before proceeding.

City of Walla Walla

The city of Walla Walla's ASR program, implemented in 1999, is the lynchpin for the city's long-term water supply planning efforts. The program has shown that recharged water can replenish portions of the region's deep basalt aquifers. In addition to seeing aquifer water levels rise, the program has also sparked a dialogue with other deep basalt water-right holders in the area regarding regional planning for groundwater use.

Walla Walla's ASR program may also prove a key tool in the city's fire fighting arsenal. Recently, the U.S. Forest Service notified the city that the 36-square mile Mill Creek Watershed is at risk for a catastrophic fire because of the buildup of combustible materials. Should a catastrophic fire erupt in the watershed, turbidity levels in Mill Creek would rise above state and federal standards. Since the city is served by an unfiltered water supply, Walla Walla would no longer be able to divert Mill Creek water for a substantial period of time. An aggressive ASR program would provide the resources and ability to counter the loss of surface water supplies with stored ASR reserves.

Currently Walla Walla's single ASR well has the capability of recharging 150-200 million gallons per year. In 2002, the city hopes to bring another ASR well on line. If the rules are finalized by that time and no new water right is required, the city would like to drill a new well which would replace the need for a large, expensive above-grade storage tank needed to supplement low pressures during the summer.

An expanded ASR program in Walla Walla will also likely have another benefit for the community and the environment. During the 2001 drought, the city was approached by the National Marine Fisheries Service to participate in an experiment to increase survivability of Endangered Species Act-listed steelhead in Mill Creek. The city voluntarily returned a portion of its appropriated surface water flow to Mill Creek and offset this loss by pumping back the balance into the distribution system using its ASR water.

Permitting status: Walla Walla has conducted the pilot test of its ASR project under a water right issued by the state of Oregon. The city intends to eventually operate its ASR project under an inchoate Washington water right permit. However, because the actual diversion of water under that permit would take place within the state of Oregon, some legal issues need to be resolved before that water right permit can be used. To date, Walla Walla has not submitted any applications for reservoir or secondary permits to Ecology.

City of Yakima

The city of Yakima commissioned a pilot test to determine the feasibility of an ASR project in the Ahtanum-Moxee sub-basin in the central part of the Yakima Basin. A pilot test conducted during the fall and winter of 2000-01 indicates that a full-scale ASR program would be both hydrogeologically and operationally feasible.

The primary source of the ASR water is the city's Naches River Rowe Hill Water Treatment Plant. The recharge well was the city's Kissel well, which is screened between 876 and 1,163 feet below ground surface, in the Lower and Middle Members of the Upper Ellensburg Formation.

Recharge to the Kissel well was conducted for 25 days at a rate of approximately 1,200 gallons per minute. A total of 45.2 million gallons was recharged. After a storage period of 55 days, recovery was conducted at a constant pumping rate of approximately 2,000 gallons per minute for 30 days. A total of 89.7 million gallons was withdrawn as part of the test, the additional amount withdrawn to ensure that there were no residual disinfection by-products. Additional water was removed during post-pilot test step tests. Water for the pilot test was delivered through the existing municipal water supply system of the city of Yakima. The distribution system operated without disruption of public service.

Recharge activities resulted in an estimated sustained rise of about six feet in the water levels of the Ellensburg Formation at the Kissel well for the two-month storage period.

Water quality monitoring indicated compliance with state drinking water standards. Although disinfection by-product concentrations did increase temporarily during storage before decreasing, they remained well below drinking water standards at all times. Based on the results of tracer analyses, it is estimated that approximately 70 percent of the water recharged to the aquifer was recovered. The remainder of the water presumably remained in the aquifer and contributed to the net storage of the hydrologic system.

A full-scale ASR program using the city of Yakima's available infrastructure is also operationally feasible. However, to increase the capacity of the groundwater supply system, additional wells would have to be installed. The permitting of these withdrawals should be easier if they are operated as part of an ASR program. Key regulatory components include:

- How ASR operations using chlorinated potable water containing disinfection by-products will be addressed under water quality standards for groundwater.
- The means of quantifying the permitted amount of water that may be recovered following recharge.

Permitting status — While Yakima and its consultant have engaged in discussions with Ecology, the city has yet to submit applications for reservoir and secondary permits. Ecology did issue the city temporary permits to conduct the pilot test.

APPENDIX C

Revised Yelm Water Balance

1.0 YELM WATERBALANCE

The Level One Technical Assessment (Level 1) (WPN, March 2002) performed a water balance analysis on all of the sub-basins in the Lower Nisqually Basin, including Yelm. The water balance for Yelm did not include credits for non-consumptive use such as reclaimed water and there were questions about the runoff values used in the original water balance analysis. This revised analysis includes reclaimed water use and uses updated runoff values for the Yelm sub-basin.

1.1 Reclaimed Water

Yelm currently reuses 200,000 gallons per day (gpd) of reclaimed water. Of that, approximately 50,000 gpd is used for groundwater infiltration. The remainder goes to stream augmentation or irrigation. In the future, up to 800,000 gpd of water will be recharged to the groundwater through infiltration.

Using data from 2002, values for monthly groundwater recharge, due to direct groundwater recharge from reclaimed water and infiltration from irrigation with reclaimed water, were calculated. These values are shown in Table A-1 and are included in this revised water balance.

1.2 Runoff

The runoff values used in the Level 1 were based on a study done in 1999 by Sinclair and Pitz, *Estimated Baseflow Characteristics for Selected Washington Rivers and Streams*. A hydrograph separation method was used on streams located in the Mashel, Tanwax/Kreger/Ohop and Muck/Murray sub-basins. No analysis was done on Yelm Creek. In the Level 1, it was assumed that percentages of surface water runoff in Muck/Murray sub-basin were similar because of similarities in topography, geology and the sizes of the sub-basin drainage areas. This does not accurately reflect the runoff values for the Yelm Sub-basin.

In this revised analysis, runoff was calculated based on the Soil Conservation Service (SCS) Runoff Method. Data on land use and soil type, available in the Level One Technical Assessment, were used to calculate a curve number for the sub-basin. The resulting curve number was 75. Using the precipitation data from the Level 1 and the calculated curve number, runoff was calculated.

1.3 Water Balance

In reassessing the water balance for Yelm, much of the information from the Level 1 was used. The precipitation data did not change. For evapotranspiration (ET) the procedure used in the Level 1 was used in this analysis. The ET values for October through April were set at the potential ET and the values for May through September were calculated so that there is no precipitation recharge during those months. Water use was based on numbers found in the Level 1 report; 20 cfs is used in October through April and 60 cfs in May through September.

The first step in the water balance is to calculate the precipitation recharge. This is the recharge that occurs from precipitation and is the remainder of the precipitation that is not lost to runoff or ET. The next step involved subtracting water use and adding water reuse to the precipitation recharge values. The resulting value, (change in groundwater storage), shows how much water is being added to or pulled from the groundwater.

1.4 Results

The results of the updated water balance can be seen in Table A-2. The most significant change is in the amount of runoff; it is higher in this revised water balance. As a result, precipitation recharge to groundwater is lower.

Seasonal recharge and build up of storage during the wet season (October through April) is sufficient to provide water during the dry season (May through September) for both water supply and maintenance of aquifer discharge boundaries. On an annual basis, the water balance shows a slightly positive (+0.5 inch) change in groundwater storage. This represents about 1% of the total precipitation and is an acceptable error in a water balance of this type. Water reuse represents an extremely small portion of the water balance, and significant increases in reuse would be necessary to gauge a measurable change to the water balance

TABLE C-1
Reclaimed Water Use for the City of Yelm

2002	Reclaimed Water (af)	Canal (af)	Recharge at Park (af)	Irrigation (af)	Recharge from Irrigation (af)	Total Groundwater Recharge (af)
January	5.0	15.1	4.7	0.3	0.2	4.9
February	4.8	12.3	4.7	0.1	0.1	4.8
March	5.2	15.0	4.7	0.5	0.3	5.0
April	5.2	13.7	4.7	0.5	0.3	5.0
May	5.3	14.9	4.7	0.6	0.3	5.0
June	8.3	11.0	4.7	3.6	2.1	6.8
July	14.3	8.4	4.7	9.6	5.5	10.2
August	12.9	10.0	4.7	8.2	4.7	9.4
September	12.2	7.5	4.7	7.5	4.3	9.0
October	9.4	10.3	4.7	4.7	2.7	7.4
November	9.2	11.5	4.7	4.5	2.6	7.3
December	6.9	12.5	4.7	2.2	1.3	6.0
Annual	98.7	142.2	56.4	42.3	24.1	80.5

1 inch of water is roughly equivalent to 2773 acre-feet of water in the Yelm Subbasin

TABLE C-2
Yelm Water Balance

	Precip (in)	ET (in)	Runoff (in)	Precip Recharge (in)	Use (in)	Reuse (in)	Change in GW Storage (in)
Oct	3.7	1.8	1.5	0.4	0.44	0.002	0.0
Nov	6.1	0.9	3.4	1.8	0.43	0.002	1.4
Dec	6.5	0.5	3.7	2.3	0.44	0.002	1.8
Jan	6.1	0.4	3.4	2.3	0.44	0.002	1.9
Feb	4.6	0.7	2.2	1.7	0.40	0.002	1.3
Mar	4.2	1.1	1.8	1.3	0.44	0.002	0.8
Apr	3.2	1.8	1.1	0.3	0.43	0.004	-0.1
May	2.2	1.7	0.5	0.0	1.3	0.003	-1.3
Jun	1.8	1.5	0.3	0.0	1.3	0.003	-1.3
Jul	0.8	0.8	0.0	0.0	1.3	0.003	-1.3
Aug	1.3	1.2	0.1	0.0	1.3	0.003	-1.3
Sep	2.3	1.7	0.6	0.0	1.3	0.002	-1.3
Annual	42.8	14.1	18.6	10.1	9.6	0.029	0.5

Notes:
1. Precipitation Data Obtained from Oregon Climate Services Prisim Map
2. ET was calculated using the same method as in the Level 1 Techinical assessment.
3. SRO was calculated using the SCS method. CN based on information available in Level 1 Technical Assessment
4. Precip Recharge = Precip-ET-SRO
5. All information for water use was obtained from Level 1 Technical Assessment
6. Information on water reuse was obtained from Skillings Connoly
7. Change GW Storage = Precip Recharge - Use - Reuse

APPENDIX C

USBR RIVERWARE RESULTS (SONNICHEN, 2003)
(CD INCLUDED)

Methow Basin Reservoir Storage Analysis Summary of Alternatives and Results

Alternative Summary

The Methow Basin Planning Unit developed seven alternatives to evaluate proposed storage in the Methow basin. The U.S. Bureau of Reclamation (Reclamation) used the river and reservoir management model RiverWare to compare the seven alternatives by using daily flows created by the U.S. Geologic Survey (USGS) Methow Basin Precipitation-Runoff Model. The 7 alternatives are divided into 3 main alternatives: 1, 2, and 3. Alternatives 2 and 3 are farther divided into 3 sub-alternatives: a, b, and c. Alternative 1 represents present conditions in the basin. Alternative 1 simulated 4,330 acre-feet (af) of existing storage in Patterson and Pearrygin Lakes and 10 major irrigation canal diversions, with current river target levels and priority constraints. Alternative 2 evaluated a larger storage level of 5,253 af of additional storage. Alternative 3 evaluated a lower storage level of 2,298 af of additional storage. The three sub-alternatives evaluated different options for using the additional storage. Sub-alternative "a" gave irrigation canals priority to river water and released storage water to maintain target flows. Sub-alternative "b" gave target flows priority to river water and released storage water to maintain canal flows. Sub-alternative "c" gave irrigation canals priority to river water and released storage water to maintain Washington State Department of Ecology (WDOE) baseflows. The different alternatives are summarized in table S1. Appendix I describes the alternatives and model configuration in detail.

Alternative Results

Table S2 summarizes the results from the seven storage alternatives proposed by the Methow Basin Planning Unit.

Appendix I - Description of Alternatives for Methow Basin RiverWare Analysis

Seven alternatives were developed by the Methow Basin Planning Unit to evaluate proposed additional basin reservoir storage. The U.S. Bureau of Reclamation (Reclamation) used the river and reservoir management model RiverWare to compare the seven alternatives, by using daily inflows created by the U.S. Geologic Surveys (USGS) Precipitation-Runoff Model for the Methow basin.

The seven alternatives included a No-Action which represents present conditions and six alternatives that evaluate the use of two basin storage volumes with three operational strategies for each storage volume. The RiverWare model simulates a basin network using operational criteria defined in a ruleset. One network was developed for the Methow River basin based on the existing and proposed features of all seven alternatives. Seven rulesets were developed from the alternative criteria. Each ruleset was run to solve the network using a 42-year daily inflow data set. The inflow data set was created from the Methow Basin Precipitation-Runoff Model created by USGS within the Modular Modeling System (MMS). The daily inflow data set is for the water years 1959 to 2001. The Methow Basin Precipitation-Runoff Model is documented in the USGS water-resources Investigations Report 01-4198.

Alternative 1: Present Conditions

Alternative 1 is the No-Action alternative and represents the present conditions regarding basin storage, diversions, target levels and water policy. Four major streams are within the study area: Chewuch River, Methow River, Twisp River, and Wolf Creek. Two streams have low flow targets defined shown in table 1. Two reservoirs are within the study area: Patterson Lake and Pearrygin Lake. Patterson Lake has an active storage capacity of 3,330 af and Pearrygin Lake has an active storage capacity of 1,000 af. Patterson and Pearrygin Lakes are primarily used for irrigation and recreation. Ten major irrigation canal systems listed in table 2 were simulated in the model. This simulation includes diversion, seepage, spill, deliveries, and return flows from each canal system. Table 2 shows the full supply requested by each canal system during the season. Table 3 shows the assumed seepage rates if the canals were at full supply. Each canal was assumed to spill 2 percent if at full supply. Delivery was simulated at the diversion less seepage and spill. The model assumed farm deliveries were 60 percent efficient. Four canal systems were split into sub-areas to allow seepage and deliveries to be split so river return flows could be more accurately represented. Seepage flows were split by canal length. Table 4 shows the canal lengths used in the model. Deliveries were split by acreage. Table 4 shows the acreages used in the model. The RiverWare model uses MMS inflows starting from the Methow River above the confluence with Wolf Creek, Chewuch River below the confluence with Falls Creek, Wolf Creek, Little Wolf Creek, Rader Creek, and Twisp River below the confluence with Buttermilk Creek, to simulate the flows to the Methow River's confluence with the Columbia. MMS flows were added at major inflow points between the starting flow points and mouth to represent local inflows. Figure 1 shows the RiverWare model network.

Wolf Creek has the one major diversion for Wolf Creek Reclamation District (WCRD), Patterson Lake feeder canal. This diversion is subject to the target flow of 8 cfs as shown in table 1. The canal from Wolf Creek has a capacity of 12.5 cfs.

Patterson Lake is operated by WCRD (WCRD has an annual storage right of 3065.6 af for Patterson Lake). Patterson Lake has a natural inflow from Rader Creek. WCRD diverts water year-round from Little Wolf Creek and seasonally (April to end of September) from Wolf Creek to meet this storage right. Patterson Lake has an active capacity of 3,330 af within the normal operational range of 25 feet. The surface area is approximately 125 acres at low pool and 150 acres at full pool. Patterson Lake was assumed to lose 1 cfs per day in seepage and 1.5 ft per year in evaporation.

Water is released out the north end of Patterson Lake to a natural drainage for diversion lower in the drainage by WCRD Canal for irrigation. The seasonal release pattern is shown in table 5. The seasonal diversion pattern for WCRD Canal is shown in table 2.

The Chewuch River has three major diversions: Chewack Canal, Fulton Canal, and Skyline Canal. The full diversion request for each canal is shown in table 2. Skyline Canal is subject to an Endangered Species Act (ESA) target flow of 80 cfs up to 2.5 cfs. Chewack Canal is reduced by 2.5 cfs to allow Skyline a total of 5 cfs when the Chewuch River is at or below the target flow. Skyline Canal has a priority to (OR OF?) 5 cfs over Chewack Canal and Fulton Canal. The 2.5 cfs of this 5 cfs is water not diverted by Chewack Canal. Chewack Canal and Fulton Canal have equal priority to water above the 5 cfs Skyline Canal flow.

Pearrygin Lake is operated by Chewack Canal Company. Pearrygin Lake has no measurable natural surface inflow. Chewack Canal Company has an annual storage right of 1,000 af. Pearrygin Lake has an active capacity of 1,000 af within the normal operational range of 5 feet. The surface area is assumed to be 200 acres at low pool and 210 acres at full pool. Pearrygin Lake seepage rate was assumed to be 0 cfs per day. Evaporation was estimated to be 1.5 feet per year.

Chewack Canal Company attempts to fill Pearrygin by May 1 with diverts from the Chewuch River beginning April 1 with the rate shown in table 2. Chewack Canal Company maintains a feeder canal from the main canal over to Pearrygin Lake that was simulated to have a capacity of 9 cfs. Currently, Chewack Canal Company maintains Pearrygin Lake full until the beginning of August. Beginning in August Chewack Canal Company lowers Pearrygin 2.5 feet by the end of each season if water was not used to meet demand on the lower system. Pearrygin Lake water is released back to the Chewack Canal via a natural drainage and feeder canal. It was assumed that the demands for the Chewack Canal sub-area were 18 cfs. If inflows to the Chewack Canal below the Pearrygin Lake return are lower than 18 cfs, then Pearrygin Lake was used to make up the difference.

The Twisp River has two major diversions, Twisp Valley Power and Irrigation (TVPI) Canal and Methow Valley Irrigation District (MVID) West Canal. A number of smaller diversions also exist on the Twisp River upstream of TVPI Canal. These diversions were simulated as one group called "Twisp Others." TVPI Canal and MVID West were simulated to have equal priority to water over "Twisp Others."

The Methow River has three major diversions: Foghorn Canal, Barkley Canal, and MVID East Canal. The seasonal full supply diversion rates for each canal are in table 2

Alternative 2a: Add 5,253 Acre-Feet Storage to Basin; Release to Target Flows

Alternative 2a simulates the additional basin storage of 5,253 af used to maintain target flows in the Twisp and Chewuch Rivers. Patterson and Pearrygin Lakes were increased by 1,500 af and 638 af respectively. Uphill Reservoir, with a 160 af capacity was added off of Skyline Canal. Elbow Coulee and Dead Horse Reservoirs were added in the Twisp River drainage, with capacities of 1,275 af and 1,680 af respectively. Table 6 is a summary of added storage to the basin.

Existing basin storage and diversions were simulated the same as in Alternative 1, with the following exceptions: The WCRD Canal capacity was increased to 20 cfs; and unused Pearrygin Lake irrigation storage was allowed to carryover to the next year.

The new storage was simulated as follows: Diversions to fill the new storage are subject to ESA target flows. The added storage in Patterson Lake was moved from Patterson to fill Elbow Coulee Reservoir via a 20 cfs pipe. If Elbow Coulee Reservoir became full, water was put into Dead Horse Reservoir via the TVPI Canal. The additional storage water in Patterson, Elbow Coulee, and Dead Horse storage were released to Twisp River to maintain a 40 cfs target flow. The additional Pearrygin Lake storage was released to the Chewuch River to maintain the 80 cfs target flow. Uphill Reservoir was used to maintain the Skyline Canal at 9.5 cfs.

Alternative 2~~a~~b: Add 5,253 Acre-Feet Storage to Basin; Release to Canals

Alternative 2a simulates the additional basin storage of 5,253 af used to maintain canal flows when the Twisp and Chewuch Rivers drop below target levels. Patterson and Pearrygin Lakes were increased by 1,500 af and 638 af respectively. Uphill Reservoir, with a 160 af capacity, was added off of Skyline Canal. Elbow Coulee and Dead Horse Reservoirs were added in the Twisp River drainage, with capacities of 1,275 af and 1,680 af respectively. Table 6 is a summary of added storage to the basin.

Existing Patterson Lake storage was simulated as in Alternative 1. The Wolf Creek feeder canal was increased to 20 cfs.

River flows were used to meet ESA target flows before diversions. The diversions to fill the storage were subject to ESA target flows. Twisp River and Chewuch River diversions in Alternative 1 were all subject to target flows in Alternative 2. Elbow Coulee and Dead Horse storage water was released to TVPI Canal when Twisp River diversions would cause gage flows to drop below target flow requirements. TVPI Canal diversions from the river were reduced, allowing "Twisp Others" and MVID West Canals to maximize river diversions to meet demands. Pearrygin Lake storage was released to Chewack Canal when Chewuch River diversions would cause gage flows to drop below target flow requirements. Chewack Canal diversions from the river were reduced, allowing Skyline and Fulton Canals to maximize river diversions to meet demands. Once storage water was depleted or a canal receiving storage water was completely turned off, then canal diversions were reduced to allow the target flow to be met. Canal diversion priorities were held the same as in Alternative 1 during turnoff.

Uphill Reservoir was operated as in Alternative 2a, using the storage water to maintain 9.5 cfs in Skyline Canal.

Alternative 2c: Add 5,253 Acre-Feet Storage to Basin; Release to Washington State Baseflows

Alternative 2a simulates the additional basin storage of 5,253 af used to maintain state baseflows in the Twisp, Chewuch, and Methow Rivers. Patterson and Pearrygin Lakes were increased by 1,500 af and 638 af respectively. Uphill Reservoir, with a 160 af capacity, was added off of Skyline Canal. Elbow Coulee and Dead Horse Reservoirs were added in the Twisp River drainage, with capacities of 1,275 af and 1,680 af respectively. Table 6 is a summary of added storage to the basin. Table 7 is a summary of the state baseflows.

Existing basin storage and diversions were simulated the same as in Alternative 1, with the following exceptions: The WCRD Canal capacity was increased to 20 cfs and unused Pearrygin Lake irrigation storage was allowed to carryover to the next year.

Additional basin storage was released to the river when gage flow dropped below state baseflow requirements.

Uphill Reservoir was operated as in Alternative 2a, using the storage water to maintain 9.5 cfs in Skyline Canal.

Alternative 3a: Add 2,298 Acre-Feet Storage to Basin; Release to Target Flows

This alternative operates the same as Alternative 2a, but has less added basin storage. The added storage is for Patterson and Pearrygin Lakes and Uphill Reservoir. The added storage in Patterson Lake is diverted over to the Twisp River via Elbow Coulee. The diversion from Patterson Lake to Elbow Coulee was limited to 20 cfs. As in Alternative 2a, the stored water is released directly to the river when the target flows are not met.

Uphill Reservoir was operated the same as in Alternative 2.

Alternative 3b: Add 2,298 Acre-Feet Storage to Basin; Release to Canals

This alternative operates the basin the same as Alternative 2b, but with only added storage for Patterson and Pearrygin Lakes and Uphill Reservoir. Water from Patterson Lake is diverted to the Twisp River via Elbow Coulee. The Patterson Lake to Elbow Coulee diversion is limited to 20 cfs. Diversions from Twisp River and Chewuch River are limited to when the targets are not met. Storage water is released to TVPI Canal and Chewack Canal from Patterson and Pearrygin Lakes respectively.

Uphill Reservoir was operated the same as in Alternative 2.

Alternative 3c: Add 2,298 Acre-Feet Storage to Basin; Release to River

This alternative is the same as Alternative 2c, but only has the added storage for Patterson and Pearrygin Lakes, and Uphill Reservoir. The added storage is released directly to the river from Patterson and Pearrygin Lakes when state baseflows downstream are not met. Patterson Lake water is released via the canal on the north end of lake. No limit was put on releases.

Uphill Reservoir was operated the same as in Alternative 2.

Table 1: ESA target flows.

Date	Wolf Creek	Chewuch River
1-Jan	0 cfs	0 cfs
1-Feb	0 cfs	0 cfs
1-Mar	0 cfs	0 cfs
1-Apr	8 cfs‡	80cfs†
16-Apr	8 cfs‡	80cfs†
1-May	8 cfs‡	80cfs†
1-Jun	8 cfs‡	80cfs†
1-Jul	8 cfs‡	80cfs†
1-Aug	8 cfs‡	80cfs†
16-Aug	8 cfs‡	80cfs†
1-Sep	8 cfs‡	80cfs†
16-Sep	8 cfs‡	80cfs†
1-Oct	8 cfs‡	80cfs†
1-Nov	0 cfs	0 cfs
1-Dec	0 cfs	0 cfs

Note:

† Skyline Canal diversion rates are dependant on the discharge in the Chewuch River meeting ESA target baseflows. During irrigation season, when the flow in the Chewuch River is greater than 80 cfs, the diversion rate is 17 cfs. If the flow in the Chewuch River drops below 80 cfs, the diversion rate to the Skyline Canal is reduced to 2.5 cfs. Also, when the flow in the Chewuch River falls below 80 cfs, the diversion to the Chewack Canal is reduced by 2.5 cfs and this water is diverted by Skyline. At the 80 cfs target Skyline may divert a total of 5 cfs.

‡ WCRD Canal diversions are subject to the ESA target baseflows on Wolf Creek. When the gage on Wolf Creek indicates the discharge is less than 8 cfs the WCRD Canal is closed.

Table 2: Canal Diversion Rates.

Date	Fulton Canal	Chewuch Canal	Skyline Canal	MVID West Canal	TVPI Canal	Twisp Others	Foghorn Canal	MVID East Canal	Barclay Canal	WCRD Canal
1-Jan	0 cfs	0 cfs	0 cfs	0 cfs	0 cfs	0 cfs	0 cfs	0 cfs	0 cfs	0 cfs
1-Feb	0 cfs	0 cfs	0 cfs	0 cfs	0 cfs	0 cfs	0 cfs	0 cfs	0 cfs	0 cfs
1-Mar	0 cfs	0 cfs	0 cfs	0 cfs	0 cfs	0 cfs	0 cfs	0 cfs	0 cfs	0 cfs
1-Apr	0 cfs	12 cfs	0 cfs	0 cfs	0 cfs	0 cfs	0 cfs	0 cfs	0 cfs	0 cfs
16-Apr	0 cfs	12 cfs	0 cfs	0 cfs	0 cfs	0 cfs	0 cfs	0 cfs	0 cfs	0 cfs
1-May	14 cfs	31 cfs	See note †	29 cfs	14 cfs	10 cfs	14 cfs	24 cfs	12 cfs	0 cfs
16-May	14 cfs	31 cfs	See note †	29 cfs	14 cfs	10 cfs	14 cfs	24 cfs	12 cfs	5 cfs‡
1-Jun	14 cfs	31 cfs	See note †	29 cfs	14 cfs	10 cfs	15 cfs	24 cfs	18 cfs	9.6 cfs‡
16-Jun	14 cfs	31 cfs	See note †	29 cfs	14 cfs	10 cfs	15 cfs	24 cfs	18 cfs	9.6 cfs‡
1-Jul	14 cfs	31 cfs	See note †	29 cfs	14 cfs	10 cfs	15 cfs	24 cfs	18 cfs	10.1 cfs‡
16-Jul	14 cfs	31 cfs	See note †	29 cfs	14 cfs	10 cfs	15 cfs	24 cfs	18 cfs	10.1 cfs‡
1-Aug	14 cfs	31 cfs	See note †	29 cfs	14 cfs	10 cfs	15 cfs	24 cfs	15 cfs	9.6 cfs‡
16-Aug	14 cfs	31 cfs	See note †	29 cfs	14 cfs	10 cfs	15 cfs	24 cfs	15 cfs	9.6 cfs‡
1-Sep	14 cfs	31 cfs	See note †	29 cfs	14 cfs	10 cfs	15 cfs	24 cfs	9 cfs	8 cfs‡
16-Sep	14 cfs	31 cfs	See note †	29 cfs	14 cfs	10 cfs	15 cfs	24 cfs	9 cfs	8 cfs‡
1-Oct	0 cfs	0 cfs	0 cfs	0 cfs	0 cfs	0 cfs	0 cfs	0 cfs	0 cfs	0 cfs
1-Nov	0 cfs	0 cfs	0 cfs	0 cfs	0 cfs	0 cfs	0 cfs	0 cfs	0 cfs	0 cfs
1-Dec	0 cfs	0 cfs	0 cfs	0 cfs	0 cfs	0 cfs	0 cfs	0 cfs	0 cfs	0 cfs

Note:
† Skyline Canal diversion rates are dependant on the discharge in the Chewuch River meeting ESA target baseflows. During irrigation season, when the flow in the Chewuch River is greater than 80 cfs, the diversion rate is 17 cfs. If the flow in the Chewuch River drops below 80 cfs, the diversion rate to the Skyline Canal is reduced to 2.5 cfs. When the flow in the Chewuch River falls below 80 cfs, the diversion to the Chewack Canal is reduced to 28.5 and the 2.5 cfs is diverted by Skyline Canal.

‡ WCRD Canal diversions are subject to the ESA target baseflows on Wolf Creek. When the gage on Wolf Creek indicates the discharge is less than 8 cfs the WCRD Canal is closed.

Table 3: Canal seepage rates.

Canal	Seepage Rate
Barkley	50%
Chewuch	50%
Foghorn	50%
Fulton	50%
MVID East	55%
MVID West	61%
Skyline	0%
TVPI	50%
Twisp Others	50%
WCRD	0%

Note: These estimates are based on measurements made by USGS and adjusted by Reclamation.

Table 4: Acreage irrigated by sub-area and canal length by sub-area for Chewuch, TVPI, and MVID Canals. Area used to split deliveries from the canal. Canal length used to split seepage for each canal.

Canal	Acreage Irrigated	Canal Length
Chewuch 1	300	2.1
Chewuch 2	980	8.8
TVPI 1	50	2.2
TVPI 2	450	1.7
MVID West 1	375	3.3
MVID West 2	375	8.2
MVID East 1	150	5.3
MVID East 2	600	5.8

Table 5: Scheduled releases from Patterson Lake to the WCRD.

Date	Patterson Lake Release to WCRD
1-Jan	0 cfs
1-Feb	0 cfs
1-Mar	0 cfs
1-Apr	0 cfs
16-Apr	0 cfs
1-May	0 cfs
16-May	8.7 cfs
1-Jun	9.7 cfs
16-Jun	9.7 cfs
1-Jul	10.4 cfs
16-Jul	10.4 cfs
1-Aug	10 cfs
16-Aug	10 cfs
1-Sep	8 cfs
16-Sep	8 cfs
1-Oct	0 cfs
1-Nov	0 cfs
1-Dec	0 cfs

Table 6: Reservoir storage volumes used in model evaluation.

Reservoir Name	Added Depth (feet)	Volume (acre-feet)
Patterson	10	1500
Pearrygin	3	638
Elbow Coulee	N/A	1275
Dead Horse	N/A	1680
Uphill	N/A	160

Table 7: Washington State regulatory baseflows for the Methow basin.

Day/Month	Lower Methow	Middle Methow	Upper Methow	Methow Headwaters	Early Winters Creek	Chewuch River	Twisp River
1-Jan	350	260	120	42	10	56	34
15-Jan	350	260	120	42	10	56	34
1-Feb	350	260	120	42	10	56	34
15-Feb	350	260	120	42	10	56	34
1-Mar	350	260	120	42	10	56	34
15-Mar	350	260	120	42	10	56	34
1-Apr	590	430	199	64	14	90	60
15-Apr	860	650	300	90	23	140	100
1-May	1300	1000	480	130	32	215	170
15-May	1940	1500	690	430	108	290	300
1-Jun	2220	1500	790	1160	290	320	440
15-Jun	2220	1500	790	1160	290	320	440
1-Jul	2150	1500	694	500	125	292	390
15-Jul	800	500	240	180	45	110	130
1-Aug	480	325	153	75	20	70	58
15-Aug	300	220	100	32	8	47	27
1-Sep	300	220	100	32	8	47	27
15-Sep	300	220	100	32	8	47	27
1-Oct	360	260	122	45	11	56	35
15-Oct	425	320	150	60	15	68	45
1-Nov	425	320	150	60	15	68	45
15-Nov	425	320	150	60	15	68	45
1-Dec	390	290	135	51	12	62	39
15-Dec	350	260	120	42	10	56	34

Table S1 - Summary Methow Basin Storage Analysis Alternatives

	Alternative 1 - 4,330 AF Existing Storage	Alternative 2 - 5,253 AF New Storage			Alternative 3 - 2,298 AF New Storage		
	Present Condition	2a Release to Targets	2b Release to Canals	2c Release to Baseflows	3a Release to Targets	3b Release to Canals	3c Release to Baseflows
Existing Patterson Lake (3,330 af)	X	X	X	X	X	X	X
Existing Pearrygin Lake (1,000 af)	X	X	X	X	X	X	X
Subordinate WCRD to Wolf Creek Target Flows	X	X	X	X	X	X	X
Subordinate Skyline Canal to Chewuch River Target Flows	X	X	X	X	X	X	X
Allow Pearrygin Reservoir Annual Carryover		X	X	X	X	X	X
Enlarged Patterson Lake (+1,500 af)		X	X	X	X	X	X
Enlarged Pearrygin Lake (+638 af)		X	X	X	X	X	X
Uphill Reservoir (160 af)		X	X	X	X	X	X
Elbow Coulee Reservoir (1,275 af)		X	X	X			
Dead Horse Reservoir (1,680 af)		X	X	X			
ESA Target Flows		X	X		X	X	
State Baseflows				X			X
Diversions have Priority (Storage used for targets/baseflows)		X		X	X		X
Targets have Priority (Storage used for diversions)			X			X	

Table S2 - Results Methow Basin Storage Analysis. Results are based on MMS inflows evaluated with RiverWare Model.

	Alternative 1 - Present Condition - 4,330 AF Existing Storage				Alternative 2 - 5,253 AF New Storage			Alternative 3 - 2,298 AF New Storage		
					2a : Release to River Target Flows	2b : Release to Canal	2c : Release to River WDOE Baseflows	3a : Release to River Target Flows	3b : Release to Canal	3c : Release to River WDOE Baseflows
	Annual Available for Storage		Average Annual Flow Shortage							
Streamflow Conditions	Target Flow	WDOE Baseflow	Target Flow	WDOE Baseflow	Target Flow		WDOE Baseflow	Target Flow		WDOE Baseflow
Methow @ Winthrop		Ave 327,330AF Min 39,300AF		28 Days 4,650AF			27 Days 4,630AF			27 Days 4,630AF
Methow @ Twisp		Ave 353,370AF Min 31,640AF		103 Days 29,330AF			100 Days 28,910AF			102 Days 29,170AF
Methow @ Pateros		Ave 359,360AF Min 25,340AF		123 Days 57,440AF			120 Days 55,610AF			122 Days 56,270AF
Chewuch @ Winthrop	Ave 123,920AF Min 9,430AF	Ave 102,180AF Min 1,420AF	49 Days 3,090AF	90 Days 7,420AF	35 Days 2,660AF	30 Days 1,320AF	87 Days 7,130AF	35 Days 2,660AF	30 Days 1,320AF	86 Days 7,100AF
Twisp @ Twisp	Ave 88,940AF Min 18,910AF	Ave 62,200AF Min 9,040AF	39 Days 1,340AF	106 Days 10,010AF	6 Days 250AF	12 Days 170AF	101 Days 9,260AF	28 Days 1,100AF	21 Days 290AF	106 Days 10,010AF
Wolf @ Winthrop	Ave 11,000AF Min 1,710AF									

	Alternative 1 - Present Condition - 4,330 AF Existing Storage	Alternative 2 - 5,253 AF New Storage			Alternative 3 - 2,298 AF New Storage		
		2a	2b	2c	3a	3b	3c
Canal Conditions	Average Annual Irrigation Delivery Shortage						
Fulton	1 Day 1AF	1 Day 1AF	26 Days 570AF	1 Day 1AF	1 Day 1AF	26 Days 570AF	1 Day 1AF
Chewack	1 Day 14AF	7 Days 5AF	7 Days 270AF	7 Days 5AF	7 Days 5AF	7 Days 270AF	7 Days 5AF
Skyline	37 Days 320AF	24 Days 210AF	20 Days 180AF	24 Days 210AF	24 Days 210AF	20 Days 180AF	24 Days 210AF
MVID East	1 Day 5AF	1 Day 5AF	0 Days 0AF	1 Day 5AF	1 Day 5AF	0 Days 0AF	1 Day 5AF
MVID West	0 Days 0AF	0 Days 0AF	14 Days 390AF	0 Days 0AF	0 Days 0AF	19 Days 670AF	0 Days 0AF
TVPI	3 Days 9AF	3 Days 9AF	0 Days 0AF	3 Days 9AF	3 Days 9AF	18 Days 150AF	3 Days 9AF

Twisp Other	9 Days 130AF	9 Days 130AF	21 Days 350AF	9 Days 130AF	9 Days 130AF	22 Days 400AF	9 Days 130AF
Foghorn	0 Days 0AF	0 Days 0AF	0 Days 0AF	0 Days 0AF	0 Days 0AF	0 Days 0AF	0 Days 0AF
Barkley	0 Days 0AF	0 Days 0AF	0 Days 0AF	0 Days 0AF	0 Days 0AF	0 Days 0AF	0 Days 0AF
WCRD	21 Days 360AF	7 Days 120AF	6 Days 100AF	13 Days 230AF	3 Days 60AF	3 Days 60AF	13 Days 220AF
	Alternative 1 - Present Condition - 4,330 AF Existing Storage	**Alternative 2 - 5,253 AF New Storage**			**Alternative 3 - 2,298 AF New Storage**		
		2a	**2b**	**2c**	**3a**	**3b**	**3c**
Storage Conditions	**Average Annual Maximum 4/1-7/31 Storage and Average Annual Sept 30th Storage**						
Pearrygin Lake	990AF 350AF	1,590AF 1,120AF	1,300AF 640AF	1,530AF 1,060AF	1,590AF 1,120AF	1,300AF 640AF	1,530AF 1,060AF
Patterson Lake	3,380AF 2,170AF	4,570AF 3,030AF	4,700AF 3,160AF	4,200AF 2,580AF	4,870AF 3,250AF	4,880AF 3,260AF	4,680AF 2,800AF
Uphill Reservoir	NA	160AF 50AF	160AF 60AF	160AF 50AF	160AF 50AF	160AF 60AF	160AF 50AF
Dead Horse Reservoir	NA	1,370AF 1,200AF	1,590AF 1,540AF	550AF 520AF	NA	NA	NA
Elbow Coulee Reservoir	NA	1,240AF 640AF	1,250AF 810AF	1,090AF 420AF	NA	NA	NA

APPENDIX D

USGS GROUNDWATER STORAGE STUDY (KONRAD, 2003)

Ground-water storage in the Methow River Basin through artificial aquifer recharge

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Ground water is an important resource in the Methow River Basin (MRB) sustaining streamflow and providing water supplies for domestic, agricultural, and commercial uses. Artificial recharge of shallow aquifers in the MRB using streamflow during high-flow periods may be able to increase ground-water storage in the basin, but its effectiveness depends on the availability of streamflow, aquifer properties at the recharge site, and ground-water levels.

Shallow ground water in the unconsolidated sediment filling the bottoms of valleys in the MRB flows into rivers, sustaining streamflow from late summer through the spring. Ground water is also used widely for domestic supplies and may be used increasingly for new residential and commercial development in the valley and for irrigation as an alternative to surface-water diversion. Unconsolidated aquifers in the Methow, Twisp, and Chewuch River valleys are recharged by a variety of sources including rivers, streams, unlined irrigation canals, and subsurface flow from surrounding hillslopes, valleys, and, possibly, deeper bedrock aquifers. Each of these sources of recharge ultimately depends on snowmelt and rainfall.

In some locations in the MRB, streamflow during high-flow periods may be used to recharge aquifers to augment streamflow and ground-water supplies later in the year. The premise for artificial aquifer recharge is that streamflow exceeds the level needed for instream uses at times and, during these times, would be available to recharge aquifers. As an initial step for assessing the availability of water for artificial aquifer recharge, daily streamflow at six stream gages was compared to Washington State regulatory base flows established to protect instream uses. The comparison is described in Section 1. The difference between streamflow and regulatory base flow represents one limitation on the water available for artificial aquifer recharge. There are likely to be other limitations, which are not assessed here, particularly in locations where a reduction in streamflow during periods of aquifer recharge has negative ecological or social impacts even if regulatory base flow is satisfied.

Shallow aquifers can be recharged artificially by distributing water over the land surface (e.g., in ponds) or in the soil column (e.g., through perforated pipes). Artificial aquifer recharge will increase the volume of ground water available for water supplies or instream uses only when three conditions are satisfied: 1) the streamflow used to recharge the aquifer would not otherwise have recharged the aquifer, 2) the aquifer is not fully saturated when streamflow is available for artificial recharge; and 3) ground water remains in the aquifer until it is needed for water supply or instream uses. To benefit instream uses, artificially-recharged ground water must continue to flow back into a river after artificial recharge has ceased for the season.

Streamflow naturally recharges the alluvial aquifer in the Methow River Basin. Artificial aquifer recharge at a given location will not increase ground-water storage if a river goes dry downstream of the location. Thus, the effective period for artificial ground-water recharge (condition 1) is limited to periods when there is streamflow downstream of a site. Condition 1 is achieved when streamflow downstream of a location exceeds regulatory base flows because regulatory base flows are greater than zero for all stations in the MRB and, consequently, is not assessed separately.

Although the shallow aquifer in the unconsolidated sediments may be confined in places, the confining units are not continuous (Konrad and others, in review), so artificial recharge is unlikely to be able to store water under more than atmospheric pressure. The availability of storage capacity in an aquifer (condition 2) is assessed by considering the depth to ground water at a site during summer when ground-water levels are typically at their annual maximum and when streamflow in excess of regulatory base flow is likely available for artificial recharge. The depth to ground water represents the approximately thickness of unsaturated material that could be used to store water.

The availability of recharged water for water supply or instream uses (condition 3) depends on the time that the water resides in the aquifer and the hydraulic effect of artificially recharged water on ground water flow. Any increase in ground-water discharge from the aquifer (or flow to parts of the aquifer where the water cannot be used) as a consequence of artificial recharge effectively reduces the net volume of water stored. Likewise, the time required for artificially recharge water to flow to a river will depend on the hydraulic conductivity of the aquifer, the hydraulic gradient between a recharge site and the river, and the distance separating the site and the river. Section 2 provides the hydraulic gradient of the regional ground-water system at each site and the horizontal length of ground-water flow paths to a point of seepage such as a river channel. Section 2 also identifies layers of fine-grained sediments in wells close to each site that are likely to have low permeabilities. These layers could impede vertical flow and, thus recharge rates. Artificially recharged ground water could also perch on these layers allowing recharged water to saturate the material above the layer and reducing the effective storage capacity of the unsaturated zone. Fine-grained layers close to the land surface also could promote shallow horizontal ground-water flow.

The response of ground-water levels to artificial recharge will need to be analyzed at a specific location before the net volume of artificially-recharged water and the storage time of that water can be estimated. In the lower Twisp River valley, ground-water mounding of 1 to 5 ft in 2 wells located between 100 and 1000 ft from an irrigation canal dissipated approximately 2 months after the flow in the canal was shut off for the season (Konrad and others, in review). Elevated gains in streamflow from the lower Twisp valley also persisted for approximately 2 months after the end of the irrigation season. Ultimately, condition 3 also depends on the time when water is needed for instream or out-of-stream uses, which is not evaluated here.

The Methow Basin Planning Unit identified six sites to investigate for artificial aquifer recharge. Two types of sites for artificial aquifer recharge were investigated: 1) floodplains and 2) terraces and valley fill deposits above floodplains. Each type of site has distinct attributes affecting its suitability for artificial aquifer recharge. Floodplains are located along rivers, so streamflow may be easily supplied to a floodplain for artificial recharge. Recharge and storage in floodplain areas are likely to be limited by a high ground-water table, lenses of fine-grained sediment with low permeability, and short ground-water flow paths back to the river. Aquifer recharge and storage in terraces and valley-fill deposits may also be limited by the same conditions, however, ground-water tables are likely to be deeper and flow paths back to rivers longer.

1. Comparison of streamflow to regulatory base flow at six gaging stations

Daily discharge records for Water Years (WY) 1992 to 2001 from six U.S. Geological Survey (USGS) stream gaging stations were analyzed to determine the volume and period when streamflow exceeded Washington State regulatory base flows. Figure 1 shows the location of the stations in relation to the aquifer-recharge sites. The six gaging stations correspond to locations downstream of eight sites that the Methow River Basin Planning Unit is considering for artificial aquifer recharge projects. The stations are:

1. Methow River above Goat Creek (USGS Station 12447383)
2. Chewuch River at Winthrop (USGS Station 12448000)
3. Methow River at Winthrop (USGS Station 12448500)
4. Twisp River near Twisp (USGS Station 1248994)
5. Methow River at Twisp (USGS Station 12449500)
6. Methow River near Pateros (USGS Station 12449950)

Washington State has established regulatory base flows at each of these stream stations for the purposes of determining the availability of water for out-of-stream uses and protecting in-stream uses of water (Washington Administrative Code 173-548-020(2)). Unlike hydrologic base flow, which represents the relatively stable discharge in a stream during periods without surface runoff, regulatory base flow is a minimum discharge used for administering the appropriation of water subsequent to the establishment of the base flow. The regulatory base flows for the 1st and 15th day of each month at each station are listed in table 1. Regulatory base flows for all other days were estimated by linear interpolation between each value in table 1.

Daily streamflow at each station from October 1, 1992 to September 30, 2002 was compared to the regulatory base flow for the respective day to determine the volume of streamflow in excess of the regulatory base flow. The period from WY 1993 to 2002 is generally representative of the long-term average of streamflow conditions in the basin as well as its inter-annual variability. Mean discharge for WY 1992 to 2002 was 1562 cfs compared to 1550 cfs for WY 1960 to 2002. The median annual discharge the Methow River near Pateros was 1647 cfs for WY 1993 to 2002 compared to 1567 cfs for WY 1960 to 2002 (table 2). Annual variation for the two periods was similar with a coefficient of variation for annual discharge of 0.36 for WY 1993 to 2002 compared to 0.33 for WY 1960 to 2002.

For WY 1993 to 2002, there was a net excess of streamflow above regulatory base flow at all six gages in the Methow River Basin (table 3). Excess streamflow ranged from 162 cfs for the Twisp River near Twisp (USGS station 12448998) to 944 cfs for the Methow River at Winthrop (USGS station 12448500). There was an annual net excess of streamflow volume in all years except WY 2001, when the total regulatory base flow for the year exceeded the total volume of streamflow at all of the stations except the Methow River at Winthrop (table 4). Daily streamflow exceeded regulatory base flow on most days in most years (table 5). The median number of days each year when streamflow exceeded regulatory base flows was 189 days for the Methow River above Goat Creek and 220 days for the Methow River near Pateros, which were the sites with the fewest number of days when streamflow exceeded state regulatory base flows. In drier years (e.g., 1993, 1994 and 2001), however, daily streamflow frequently did not meet regulatory base flow at many stations in the MRB.

Figure 2 shows the frequency (number of years) that daily streamflow at each station exceeded regulatory base flow. At most stations, daily streamflow exceeded regulatory base flow from March through July. Notable exceptions when streamflow was less than regulatory base flow in most years include: all stations during September except the Methow River at Winthrop (12448500); and the Methow River above Goat Creek (12447383), the Methow River at Twisp (12449500), and the Methow River near Pateros (12449950) from September through March.

There were days in every year when streamflow exceeded regulatory base flow. The annual volume of streamflow for days when streamflow exceeded regulatory base flow ranged from 9,000 acre ft for the Chewuch River at Winthrop in WY 2001 to 1,090,000 acre ft for the Methow River near Pateros in WY 1999 (table 6). Although streamflow exceeded regulatory base flow on some days during the 2001 drought, the total volume of streamflow in excess of state regulatory base flow was limited.

2. Hydrologic conditions related to artificial aquifer recharge at six sites of the Methow River Basin

Hydrologic conditions were investigated at six sites in the MRB as an initial assessment of the potential for artificial aquifer recharge. The general locations of the six sites in the basin are shown in figure 1. Sites 1-3 are located on floodplains along the Methow or Twisp Rivers (table 7, figs. 3-5). Sites 4-6 are located on terraces or valley-fill deposits above floodplains (table 7, figs. 6-8).

Depth to ground water, hydraulic gradient, and distance along the subsurface flow path to the nearest river channel were determined for each site. Depth to ground-water was determined from water level measurements using a geographic information system (GIS). A raster (grid) coverage (10 m cells) of ground-water elevations for the unconsolidated deposits was interpolated from ground-water levels for 254 wells measured in June and July 2001, which represents seasonally high ground-water levels, (Konrad and others, in review) and land surface elevations for 29 points along rivers taken from the National Elevation Dataset (NED) (USGS, 2003). The resulting raster coverage of ground-water elevations was used to estimate the hydraulic gradient between each site and either the Methow or Twisp River.

Horizontal flow paths were determined by manually digitizing lines from the boundary of the each site perpendicular to equipotential (contour) lines of the ground water to the point of intersection with a river. The actual flow paths have a vertical component and are likely to deviate from the paths depicted because of variation in the hydraulic conductivity within the unconsolidated sediment. As a result, actual flow paths are likely to be longer than the estimates presented here.

The raster coverage of ground-water elevations was subtracted from the NED land-surface elevations for the valley floor to produce a raster coverage of depth to ground water. Contours corresponding to 3 ft, 10 ft, and 20 ft depths were manually digitized from the raster coverage of depth to ground water.

Well reports for wells in and near each site [Washington Department of Ecology, 2003] were reviewed to characterize the local lithology and any fine-grained sediments that could represent low-permeability layers. Wells are referred to by their Township, Range, Section, and a letter identifying the quarter-quarter section with "A" representing the northeast quarter of the northeast quarter section, "D" representing the northwest quarter of the northwest quarter, "N" representing the southwest quarter of the southwest quarter section, and "R" representing the southeast quarter of the southeast quarter section. "I" is omitted from quarter-quarter section identifiers. If the well has been inventoried by USGS, then a sequence number follows the quarter-quarter section identifier.

Soil information for sites 2, 4, 5, and 6 was compiled from the Soil Conservation Service (1980). Soils at the other sites were not mapped by Soil Conservation Service.

Sites 1-3 were surveyed in April 2003 to locate the primary side channels, water surfaces, and elevations of the side channels relative to the adjacent river channels. A TOPCON total station and HP48GX/TDS surveying system was used. Surveys at sites 1 and 2 included nearby benchmarks to georeference the surveyed points. A handheld global positioning system (GPS) receiver was used to obtain the approximate geographic coordinates of the surveyed points in site 3.

2.1. Methow River above Early Winters Creek

The floodplain southwest of the Methow River has a braided side-channel network approximately 1.5 miles upstream of Early Winters Creek (fig. 3). The network extends over approximately 45 acres (table 8) with as many as four distinct, parallel channels in places. There are multiple entrances where water flows into the network during high flows. The main side channel is 3,900 ft long (table 9). The median combined width of the side channels at their banks is 83 ft for three cross-sections.

The unconsolidated sediments in valley are 3,400 ft wide at the land surface and more than 850 ft thick at the valley center (for example, well 36N/19E-22C [E-12]). The sediments are mostly coarse (gravel, sand, cobbles, some clay) (table 10). Depth to ground water ranged from more than 10 ft to less than 3 ft (fig. 9). Small, discontinuous areas of standing water were observed at six locations in the side-channel network in April 2003. The source of this water was not certain, but it may have been seepage of shallow ground-water, which was perched on fine-grained facies deposited in the side-channel network. Fine-grained layers, described as "silt" or "hardpan" with top elevations ranging from 2,158 to 2,168 ft (table 10), were identified in four wells near to the site. These layers are 19 to 46 ft below the land surface, which is deeper than the ground-water table in most locations, and similar fine-grained layers were not reported in two other wells west of the site. Although there is not a continuous layer of fine-grained material at the site, there may be shallow, discontinuous lenses of fine-grained material which could limit aquifer recharge in places. Ground water generally flows away from the river in the northern part of the site and toward the river at the southern end. The length of horizontal flow paths between the site and the river ranges from 1,800 ft to 1 mile (fig. 3). The hydraulic gradient between ground-water at the site and the Methow River along the flow paths is 0.01.

2.2. Methow River at Fawn Creek

The floodplain southwest (right) of the Methow River has a series of side channels that begins 0.5 miles upstream of the confluence with Fawn Creek (fig. 4) and covers about 62 acres (table 8). A levee along the right (facing downstream) river bank limits inflows to the side-channels to two culverts and ground-water seepage (through the levee or from the alluvial aquifer). The main side channel is 5,600 ft long. It has been used to convey water from the Methow River to two irrigation canals. The median combined width of the side channels at their banks is 65 ft for six cross-sections, however, the cross-section did not include all side channels.

The unconsolidated sediments are 4,000 ft wide at the land surface and 860 ft thick on the southern side of site (for example, well 36N/20E-04N [E-10]). The sediments are coarse (cobbles, sand, and gravel). Depth to ground water is less than 3 ft (fig. 9): ground-water seepage into the side channels and surface-flow were observed throughout the site in April 2003. Three logs were available for wells near to the site. The log of one well in the site (35N/20E-04N01) reported the top of a "silt and gravel" layer at an elevation of 1,978 ft. A well log close to the site (35N/20E-10E01) reported the top of a "clay" layer at an elevation of 1,969 ft. Ground water generally flows toward the river with a path length from the site to the river from less than 100 ft to 1.5 miles (fig. 4). The hydraulic gradient between ground water at the site and the Methow River ranges along the flow paths from 0 (ground-water and surface-water levels are equal) to 0.006. Soils at the site include xerofluvent, Boesel fine sandy loam, and river wash [table 7, SCS, 1980].

2.3. Twisp River at War Creek

The floodplain northwest of the Twisp River has a large side channel that begins approximately 500 ft upstream of the confluence with War Creek. It served as the main channel for the Twisp River, as depicted in the Oval Peak 7.5 minute quadrangle topographic map of 1969 (fig. 5). The side channel branches downstream, forming a distributary network that is more than 1000 ft wide and covers about 50 acres (table 8). The main side-channel is 3,300 ft long. The median combined width of the side channels at their banks is 144 ft for three cross-sections.

The unconsolidated sediments are 2,000ft wide and more than 100 ft thick toward the valley wall. They are likely thicker in the center of the valley under the river. The sediments are mostly coarse sand, gravel. No ground-water levels were available for this site, but based on the water surface in the river, depth to ground-water is likely to range from 3 to 10 ft below the land surface, though it may be shallower at the upstream and downstream ends of the site (fig. 11). No standing water was observed at the site in April 2003. The report for the well at the edge of the study area (33N/20E-07N01) identified the top of "river sand and blue clay" at an elevation of 2,306 ft (depth of 102 ft) and the top of "clay and sandstone" at an elevation of 2,291 ft (depth of 117 ft) (table 10). These layers are unlikely to affect artificial recharge due to their depth, however, there may be other fine-grained lenses closer to the land surface at the site. The primary direction of ground-water flow is likely down valley (fig. 5), in which case, horizontal flow paths would be approximately 3,200 ft. The hydraulic gradient between the site and the river is estimated be 0.01.

2.4. Big Twin Lake

Big Twin Lake is a 77-acre lake formed in a closed depression on a glacio-lacustrine terrace 2 miles south of Winthrop (fig.7). The unconsolidated sediments are more than 100 ft thick in the center of the terrace and poorly sorted (clay, silt, sand, gravel, cobble, and boulders) and may fill a paleo-channel that is approximately 3,000 ft wide in the bedrock beneath the terrace (Konrad and others, in review). The water-surface elevation in the lake is approximately the same as ground-water levels in surrounding shallow wells. Depth to ground-water increase to more than 20 ft at a distance of 100 to 1,000 ft from the lake shore as the land surface rises away from the lake. The saturated thickness of the unconsolidated aquifer is more than 100 ft southeast of the lake (well 34N/21E-15R01). Potential low-permeability layers were reported in 5 of 6 well logs with tops of the layers reported at an elevation of 1,818 to 1,832 ft in four wells. These layers may not have been continuous, however, as they were reported variously as "clay like" at an elevation of 1,818 ft, "silt" at an elevation of 1,822 ft , "clay" at an elevation of 1,825 ft, and "clay and gravel" at an elevation of 1,832 ft (table 10). Ground water generally flows to the southwest with horizontal flow paths to the Methow River that are likely 1.5 to 2 miles long. The hydraulic gradient between ground water at the site and the Methow River along the flow paths ranges from 0.011 to 0.015 . The soil is Owhi extremely stony fine sandy loam with a permeability of 2 to 6 inches per day [SCS, 1980].

2.5. Elbow Coulee

Elbow Coulee is a north-south trending valley, north of the Twisp River between Newby and Poorman Creeks (fig. 6). The valley was likely formed through erosion by glacial ice and melt water. The valley is filled with poorly sorted, unconsolidated sediments (clay, silt, sand, gravel, cobble, and boulders) that are at most 800 ft wide at the land surface with a total thickness of approximately 50 ft and a saturated thickness of approximately 10 ft at its southern end. The depth to ground-water is generally more than 20 ft (fig. 13). Ground-water levels may be closer to the land surface in the upper (north) part, but there are no wells in this part of Elbow Coulee that could confirm this. Ground water flows to the south, down Elbow Coulee toward the Twisp River. Unconsolidated sediments form a terrace along the north side of the Twisp River that is continuous with the sediments filling Elbow Coulee. Ground water seeps from the east side of the base of the terrace to a wetland area adjacent to the river. Ground-water flow paths to the river range from about 1,200 ft at the lower end of Elbow Coulee to about 2.3 miles at the upper end (fig. 6). The hydraulic gradient between ground water in the lower portion of Elbow Coulee and the Twisp River is 0.03. The soil in Elbow Coulee is Newborn gravelly loam, with a permeability of 0.6 to 20 inches per day [SCS, 1980].

2.6. Terrace southeast of Twisp

A terrace formed of coarse unconsolidated sediments (sand and gravel) with a thickness of 80 to more than 100 ft is located 1.5 miles southeast of Twisp on the northeast side of the Methow River (fig. 8). The terrace was deposited over bedrock forming the divide between the Methow River and Beaver Creek. The depth to ground water is more than 20 ft under the terrace (fig. 14) with two wells (33N/21E-16R [6"] and [8"] in the terrace having depths to water of 71 and 84 ft. The ground-water surface under the terrace is higher, by approximately 40 ft, than the ground-water in the alluvial deposits along the Methow River to the west. The saturated thickness of the unconsolidated aquifer in these wells ranges from 10 to more than 19 ft. The bedrock surface below the terrace is likely to dip to the southwest toward the Methow River. Ground-water flow paths from the terrace to the river are likely 1,100 to 3,100 ft. (fig. 7). The hydraulic gradient between ground water at the site and the Methow River along the flow paths ranges from 0.007 to 0.02. The soils on the terrace are Newbon gravelly loam, Winthrop gravelly loamy sand, and Newbon loam, which have permeabilities ranging from 0.6 to more than 20 inches per day [SCS, 1980].

3. Hazards of artificial recharge

Artificial aquifer recharge can be expected to increase ground-water levels, ground-water flow rates, and associated hazards. Specific hazards of artificial aquifer recharge were not assessed at any of the sites, but some likely hazards are listed. In general, increased ground-water levels will increase any associated flooding from ground-water seepage and hillslope instability. Increased ground-water levels can also mobilize and transport contaminants from previously unsaturated soils into ground water. This is particularly a hazard if artificial aquifer recharge raises ground-water to a level where waste has been buried and around drain fields for septic systems. The terrace south of Twisp (site 6) includes a closed Okanogan County landfill. Buried wastes at site 6 represent a potential source of contaminants that artificial recharge could mobilize. Septic effluent from residences around the Twin Lakes area (site 4) could also contaminate ground water if artificial recharge increased ground-water levels to the point that drain fields were saturated by the artificially recharged water. Contaminants on the land surface may also be transported by water infiltrating into soils, for example, where hazardous material are stored or airborne contaminants deposit on the land surface.

4. Summary and conclusions

Artificial aquifer recharge represents one approach for re-distributing water resources in the Methow River Basin from periods of high runoff during the late spring and early summer to periods of low runoff later in the summer and into the winter. Annual streamflow volume exceeds regulatory base flow volume in all but drought years (e.g., WY 2001) at the six gages where regulatory base flows have been established in the MRB. Overall, the reliability of excess streamflow is highest during late spring and summer for all gages: streamflow exceeded regulatory base flow from May through August at all gages for 7 out 10 years in the period from WY 1993 to 2002 and may be a reliable period for using streamflow for artificial aquifer recharge. Streamflow was commonly (fewer than 5 out of 10 years) less than regulatory base flow from September through March for the Methow River above Goat Creek, the Methow River at Twisp, and the Methow River near Pateros. Streamflow in the Chewuch River at Winthrop and the Twisp River near Twisp was frequently less than regulatory base flow during September. It is unlikely, then, that surface-water diversions could be used from September through March for artificial aquifer recharge.

The hydrogeology of unconsolidated sediments in the Methow River basin varies spatially with regard to a number of important conditions that could affect aquifer recharge including depth to ground water, hydraulic gradient, and length of flow paths to a river. Ground water levels near the Methow River above Early Winters and the Twisp River at War Creek are likely deep enough to allow artificial aquifer recharge throughout the year except for periods of sustained high streamflows in some years. Ground water at the Methow River at Fawn Creek is relatively shallow. As a result, there is little storage capacity available in the aquifer and any water artificially recharged is likely to flow along shallow, horizontal paths quickly back to the river.

Ground-water levels at Big Twin Lake, Elbow Coulee, and the terrace south of Twisp are likely to be deep enough to allow artificial recharge throughout the year and, in particular, during periods of high flows when streamflow generally exceeds state regulatory base flow. The closed landfill south of Twisp, however, represents a potential source of contaminants that artificial aquifer recharge could mobilize and transport. In comparison to the terrace south of Twisp, Big Twin Lakes and Elbow Coulee have long ground-water flow paths that would delay the return of artificially-recharged water to the Methow and Twisp Rivers, respectively. Streamflow in excess of regulatory base flow may be available for artificial aquifer recharge in most years from April through August except, however, during late June and early July for the Methow River near Pateros and the Twisp River near Twisp.

gradient x T

Artificial aquifer recharge can be expected to increase ground-water levels and ground-water flow at and around a recharge site. As a result, the total volume of water artificially recharged will be reduced by the increase in ground-water flow rate over time. Likewise, the increase in ground-water discharge to a river as a consequence of artificial recharge will persist only as long as ground-water levels are elevated by the artificial recharge. The response of the ground-water system to artificial recharge will need to be analyzed at a specific location before the net volume of artificially-recharged water can be estimated.

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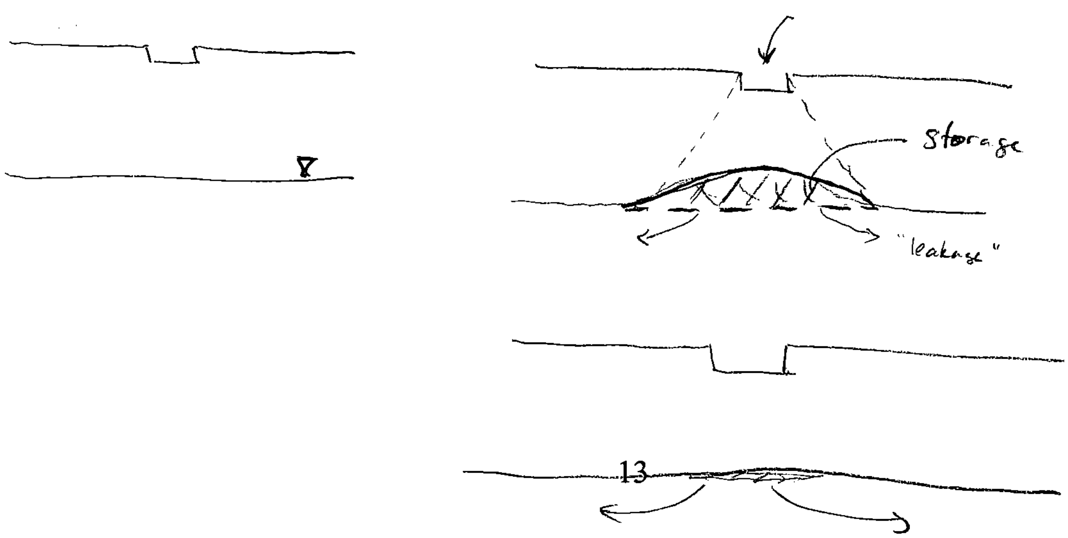
In general, an aquifer would likely support additional ground-water flow under artificial recharge without substantial ground-water mounding where the aquifer is wide and has a large saturated thickness, a high hydraulic gradient, and high hydraulic conductivity. Based on these conditions, the floodplain sites and Big Twin Lake are likely to have least mounding in response to aquifer recharge. Any mounding at the floodplain sites, however, could result in shallow, horizontal ground-water flow back to the river particularly for the Methow River at Fawn Creek where ground water is naturally shallow. Overall, artificial recharge at the Methow River above Early Winters Creek, the Twisp River at War Creek, and Big Twin Lake is less likely cause changes in ground-water flow than at other sites and artificially-recharged ground-water can be expected to flow at the same velocities and along the same paths as the existing ground-water system.

The same factors that prevent mounding, however, also limit the temporary increase in streamflow that may result after a period of artificial aquifer recharge. As a consequence, artificial recharge at these sites may not cause a seasonal increase streamflow, even as they may contribute a small but steady component of ground-water inflow to downstream river reaches. In contrast, artificial recharge at Elbow Coulee and the terrace south of Twisp might produce the largest seasonal (temporary) increase in streamflow of any of the sites after periods of artificial recharge because of mounding that would increase the already high hydraulic gradients between these sites and the respective rivers. Elbow Coulee has potentially longer flow paths back to the Twisp River than the terrace south of Twisp does to the Methow River. The longer flow paths could provide a longer delay between periods of artificial recharge and inflow back to the river assuming similar hydraulic conductivity and gradients at the two sites.



mounded system
high S, high time lag,

low mounding
low S,
low time lag

5. References

Konrad, C.P., Drost, B.W., and Wagner, R.J., in review, The hydrogeology of the unconsolidated deposits, water quality, and ground-water surface-water exchanges in the Methow River Basin, Okanogan County, Washington, U.S. Geological Survey, Water-Resources Investigations Report 03-XXXX, x p.

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U.S. Forest Service, 1998d, Digital orthophoto of the Winthrop quadrangle, image taken on July 8, 1998, http://rocky.ess.washington.edu/data/raster/usfs/concrete/images/48120c1_1998.zip accessed on October 17, 2002.

U.S. Forest Service, 1998e, Digital orthophoto of the Twisp East quadrangle, image taken on July 8, 1998, http://rocky.ess.washington.edu/data/raster/usfs/concrete/images/48120c4_1998.zip accessed on October 17, 2002.

Table 1. Comparison of streamflow conditions for the Methow River near Pateros (USGS station 12449950) for WY 1959.

	WY 1960-2002	WY 1993-2002
Mean	1550 cfs[1]	1562 cfs
Median	1567 cfs	1647 cfs
Minimum	565 cfs	576 cfs
Maximum	3413 cfs	2251 cfs
Coefficient of variation of daily mean discharge	1.5	1.5

[1]cubic feet per second

Table 2. Washington regulatory base flows at six locations in the Methow River Basin.

Day of the year	Methow River above Goat Creek (USGS Station 12447383)	Chewuch River at Winthrop (USGS Station 12448000)	Methow River at Winthrop (USGS Station 12448500)	Twisp River near Twisp (USGS Station 12448998)	Methow River at Twisp (USGS Station 12449500)	Methow River near Pateros (USGS Station 12449950)
			cubic feet per second			
1-Oct	45	56	122	35	260	360
15-Oct	60	68	150	45	320	425
1-Nov	60	68	150	45	320	425
15-Nov	60	68	150	45	320	425
1-Dec	51	62	135	39	290	390
15-Dec	42	56	120	34	260	350
1-Jan	42	56	120	34	260	350
15-Jan	42	56	120	34	260	350
1-Feb	42	56	120	34	260	350
15-Feb	42	56	120	34	260	350
1-Mar	42	56	120	34	260	350
15-Mar	42	56	120	34	260	350
1-Apr	64	90	199	60	430	590
15-Apr	90	140	300	100	650	860
1-May	130	215	480	170	1000	1300
15-May	430	290	690	300	1500	1940
1-Jun	1160	320	790	440	1500	2220
15-Jun	1160	320	790	440	1500	2220
1-Jul	500	292	694	390	1500	2150
15-Jul	180	110	240	130	500	800
1-Aug	75	70	153	58	325	480
15-Aug	32	47	100	27	220	300
1-Sep	32	47	100	27	220	300
15-Sep	32	47	100	27	220	300

Table 3. Difference between daily streamflow and state regulatory base flow for WY 1993-2002.

Methow River above Goat Creek	319 cfs[1]
Chewuch River at Winthrop	287 cfs
Methow River at Winthrop	917 cfs
Twisp River near Twisp	153 cfs
Methow River at Twisp	855 cfs
Methow River near Pateros	781 cfs

[1]cubic feet per second

Table 4. Annual net volume of streamflow in excess of WA regulatory base flows. Negative values indicate that annual streamflow was less than regulatory base flow.

Water Year	Methow River above Goat Creek	Chewuch River at Winthrop	Methow River at Winthrop	Twisp River near Twisp	Methow River at Twisp	Methow River near Pateros
			thousands of acre feet			
1992	159	80	443	51	360	244
1993	89	118	403	44	297	199
1994	73	122	362	31	263	156
1995	293	300	859	168	880	801
1996	365	302	951	218	998	946
1997	391	339	1000	200	1003	999
1998	292	288	844	135	820	844
1999	443	374	1065	170	1036	1088
2000	227	160	586	101	556	501
2001	-24	-8	124	-6	-22	-124

Table 5. Number of days each Water Year (WY) when streamflow exceeded regulatory base flows.

Water Year	Methow River above Goat Creek	Chewuch River at Winthrop	Methow River at Winthrop	Twisp River near Twisp	Methow River at Twisp	Methow River near Pateros
1992	179	321	366	312	324	216
1993	106	196	337	211	130	116
1994	94	286	365	158	157	89
1995	198	285	365	335	234	220
1996	321	365	366	366	366	358
1997	193	365	365	365	361	333
1998	250	365	365	354	354	364
1999	189	365	365	365	310	325
2000	247	350	366	354	351	353
2001	26	85	326	152	66	15
Median	189	321	365	335	310	220

Table 6. Annual volume of streamflow in excess of regulatory base flow for days when streamflow exceeded regulatory base flows.

Water Year	Methow River above Goat Creek	Chewuch River at Winthrop	Methow River at Winthrop	Twisp River near Twisp	Methow River at Twisp	Methow River near Pateros
			thousands of acre feet			
1992	174	81	444	55	362	259
1993	122	127	408	53	347	301
1994	105	124	362	41	279	215
1995	308	301	859	169	894	826
1996	370	303	953	218	1001	949
1997	403	339	1000	200	1003	1001
1998	297	288	844	135	821	844
1999	460	374	1065	170	1039	1090
2000	232	160	588	101	558	503
2001	25	9	133	12	55	32

Table 7. Sites investigated for potential artificial aquifer recharge.

	Site	Landscape feature	Soils
1	Methow River above Early Winters Creek	Floodplain	Not available[2]
2	Methow River at Fawn Creek	Floodplain	Xerofluvents, Boesel fine sandy loam, and riverwash[1]
3	Twisp River at War Creek	Floodplain	Not available[2]
4	Big Twin Lake, Winthrop	Glacial terrace	Owhi extremely stony fine sandy loam[1]
5	Elbow Coulee, Twisp River below Newby Creek	Glacio-fluvial valley-fill deposit	Newbon gravelly loam[1]
6	Terrace southeast of Twisp, Methow River above Beaver Creek	Glacio-lacustrine terrace	Newbon gravelly loam, Winthrop gravelly loamy sand, Newbon loam[1]

[1]Source: Okanogan County Soil Survey (Soil Conservation Service, 1980).
[2]Not included in the Okanogan County Soil Survey, but likely to have riverwash and Boesel fine sandy loam.

Table 8. Maximum recharge rates for sites based on total acreage and representative infiltration rate for soil types.

Site	Acres	Infiltration rate[1] (inches per day)	Maximum recharge rate for site (acre ft per day)
Methow River above Early Winters Creek	44.5	3	267
Methow River at Fawn Creek	61.7	3	370
Twisp River at War Creek	49.8	3	299
Big Twin Lake, Winthrop	77.6	4	621
Elbow Coulee, Twisp River	85.6	1.3	222
Terrace southeast of Twisp, Methow River above Beaver Creek	54.6	5	546

[1]Source: Okanogan County Soil Survey (Soil Conservation Service, 1980).

Table 9. Dimensions of side channels at sites 1-3.

Site	Maximum length (ft)	Median width of channels at bank (ft) with number of cross-sections in [ ]	Area covered by side channels (acres)
Methow River above Early Winters Creek	3900	83 [3]	7.5
Methow River at Fawn Creek	5600	65 [6]	8.3
Twisp River at War Creek	3300	144 [3]	10.9

Table 10. List of wells near sites with top elevations of land surface and potential low-permeability layers. Datum for all elevations is NAVD 1988.

Local well numbers[1]	Land surface (ft)	Principal lithology	Top elevation of potential low-permeability layers (ft)
Methow River above Early Winters Creek			
36N/19E 22C [E-12]	2205	Boulders, sand, gravel	Unconsolidated sediments not differentiated
36N/19E-15L02	2214	Gravel, clay, hardpan, sand	2200 (clay), 2191 (hardpan), 2168 (hardpan)
36N/19E-15K [MW-1B]	2208	Sandy cobbles, gravel	2163 (silt)
36N/19E-22J01	2179	Gravel, boulders, silt, sand	2160 (silt)
36N/19E-22J02	2179	Silt, gravel, hardpan, sand	2158 (hardpan)
36N/19E-23E02 [EW19]	2197	Boulders, sand, gravel	None
36N/19E-23E03 [EW19A]	2197	Sand, gravel, boulders	None
Methow River at Fawn Creek			
36N/20E-04N [E-10]	1999	Not differentiated	Unconsolidated sediments not differentiated
35N/20E-04N01	2010	Cobbles, sand, gravel, silt	1978 (silt and gravel)
35N/20E-10E01	1974	Clay, sand, and gravel	1969 (clay)
Twisp River at War Creek			
33N/20E-07N01	2408	Sand, gravel, and boulders	2306 (river sand and blue clay), 2291 (clay and sandstone)
Twin Lakes			
34N/21E-15B01	1894	Sand, gravel, clay	1825 (clay)
34N/21E-15R01	1886	Till, sand, gravel	1886 (till)
34N/21E-15E01	1954	Clay, gravel, hardpan, bedrock	1938 (clay)
34N/21E-14D01	1844	Sand, gravel, bedrock	None
34N/21E-14E01	1853	Silt, sand, cobbles, gravel	1838 (cemented silt), 1818 (clay like)
34N/21E-14N01	1864	Clay, sand, gravel, silt, bedrock	1864 (clay), 1822 (silt)
34N/21E-14P01	1864	Sandy clay, gravel, bedrock	1821 (bedrock)
Elbow Coulee			
33N/21E-09D01	1974	Sand, gravel, clay	1962 (clay)
33N/21E-09D02	2004	Gravel, silt, cobbles, boulders, clay, bedrock	1974 (clay)
33N/21E-09D03	1969	Gravel, hardpan, clay	1969 (clay and gravel)

Table 10 continued.

Local well numbers[1]	Land surface (ft)	Principal lithology	Elevation of potential low-permeability layers (ft)
Terrace southeast of Twisp			
33N/21E-16P01	1584	Silty sand, cobbles, gravel	1554 (sand, silty; tight clay-like)
33N/21E-16R03	1673	No well log	No well log
33N/21E-16R	1673	Sand, gravel, cobbles, boulders, clay	1632 (fine to medium sand, abundant clay)
33N/21E-16R	1657	Gravel, cobbles, boulders, sand, bedrock	None

[1]Local well numbers are the Township, Range, Section, and a letter identifying the quarter-quarter section of the well described in the text. If the well has been inventoried by USGS, then a 2-digit sequence number follows the quarter-quarter section identifier. Other agency codes for wells are listed in [ ].

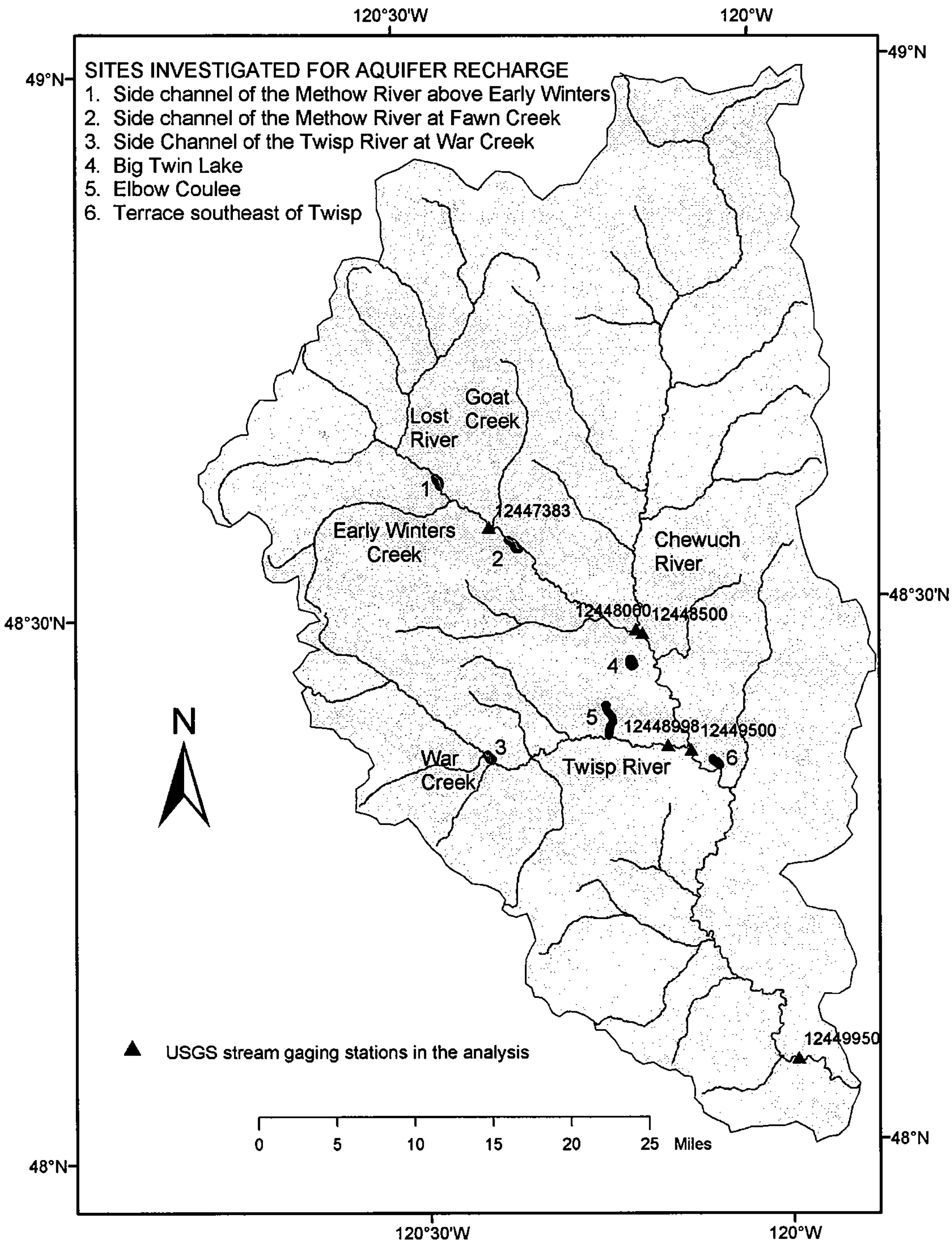
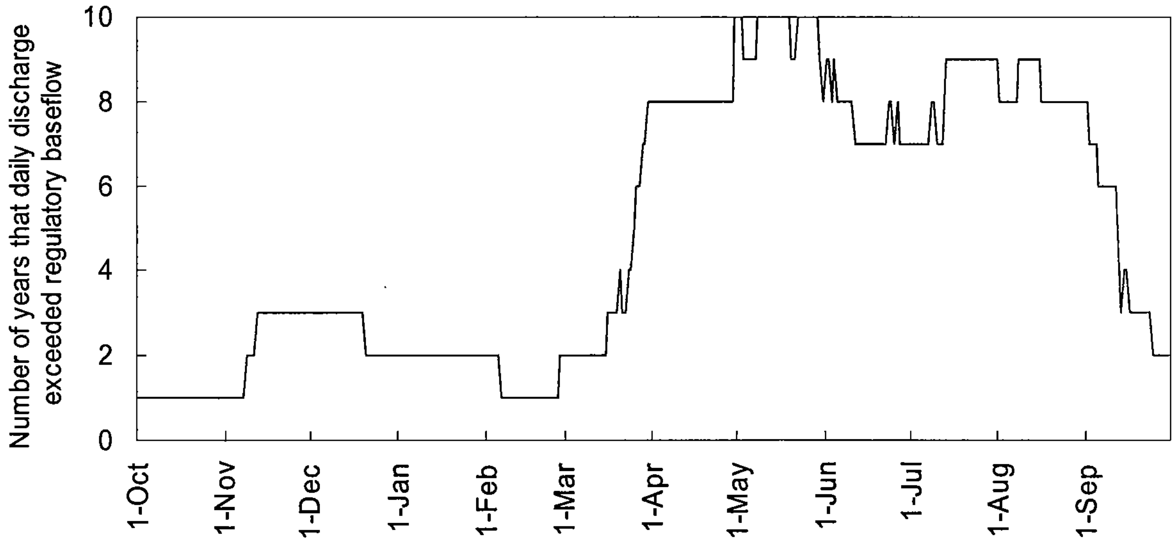
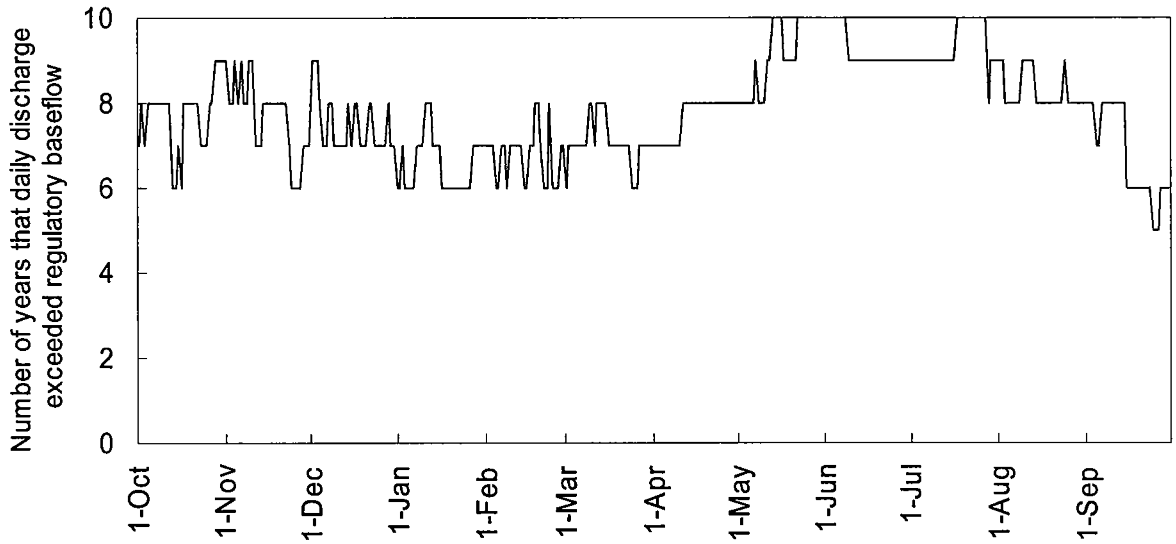


Figure 1. Methow River Basin with selected USGS stream gaging stations and sites investigated for artificial aquifer recharge.

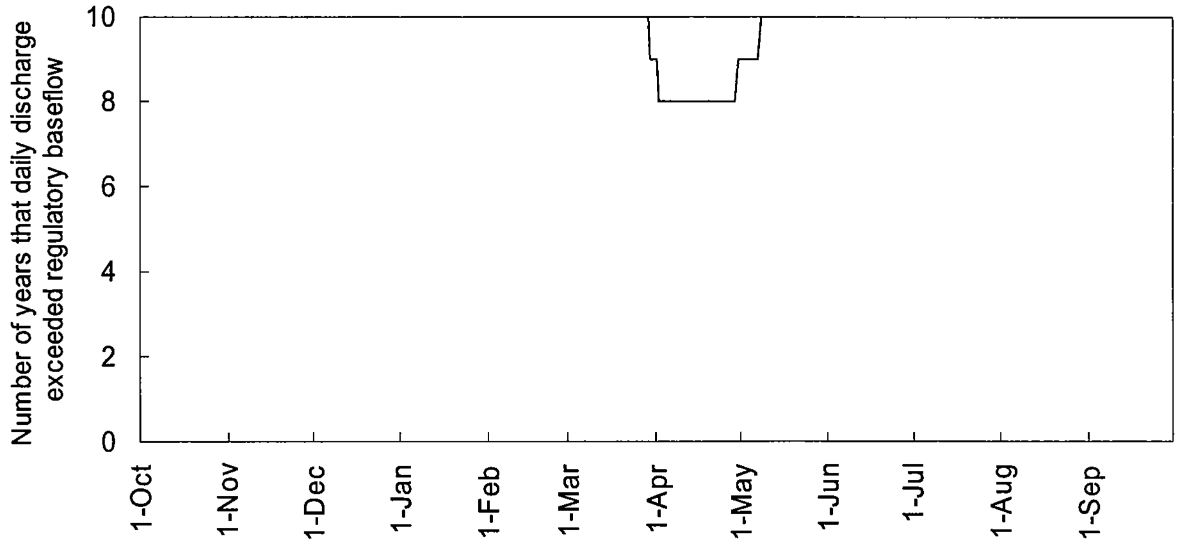


a. Methow River above Goat Creek (USGS station 12447383)

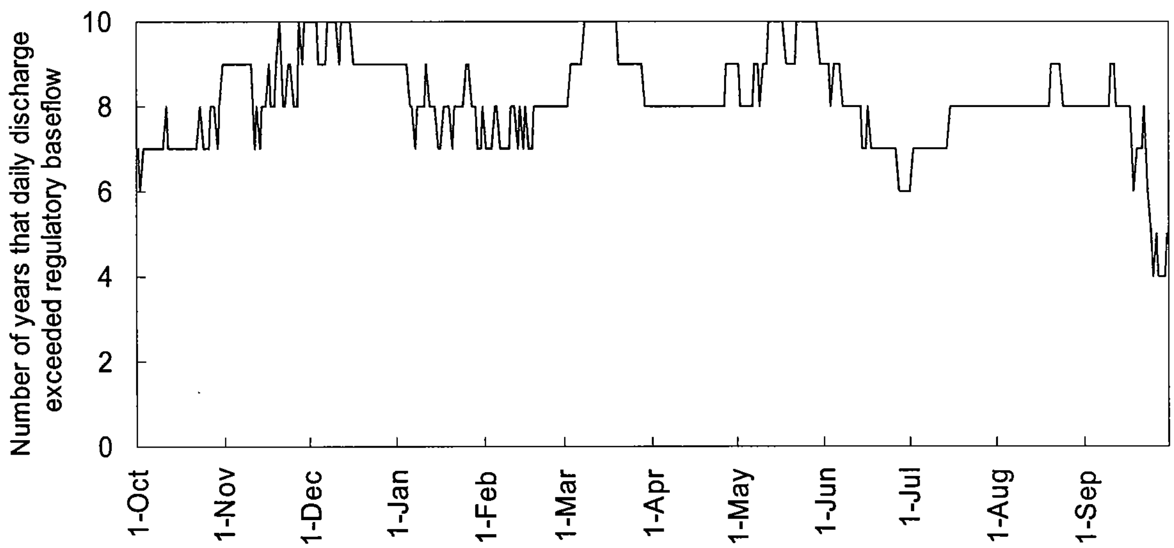


b. Chewuch River at Winthop (USGS station 12448000)

Figures 2a and 2b. Frequency that daily discharge exceeded regulatory base flows at the Methow River above Goat Creek and the Chewuch River at Winthrop for Water Years 1993 to 2002.

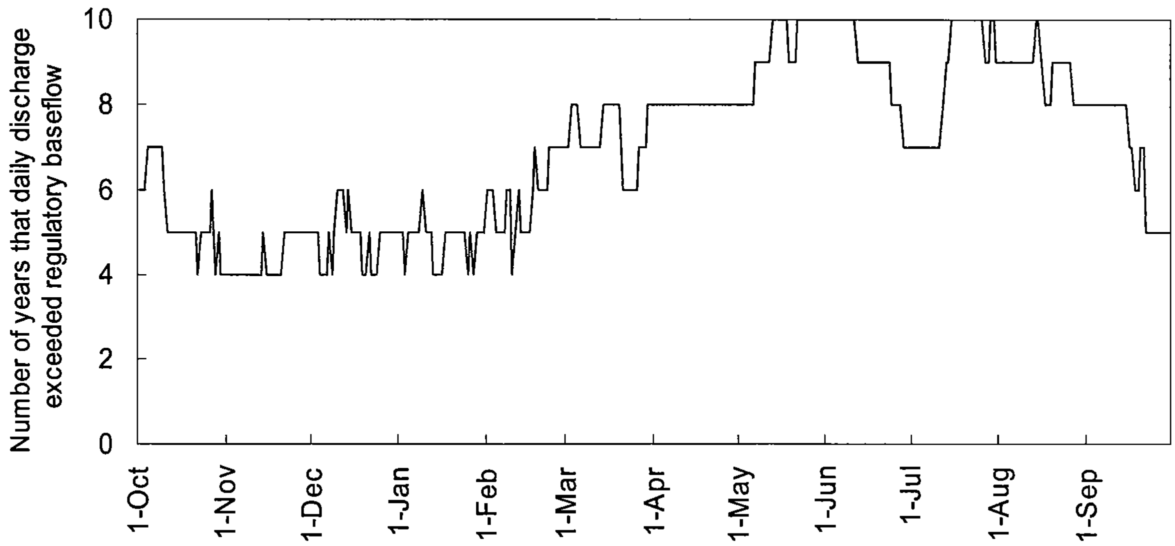


c. Methow River at Winthrop (USGS station 12448500)

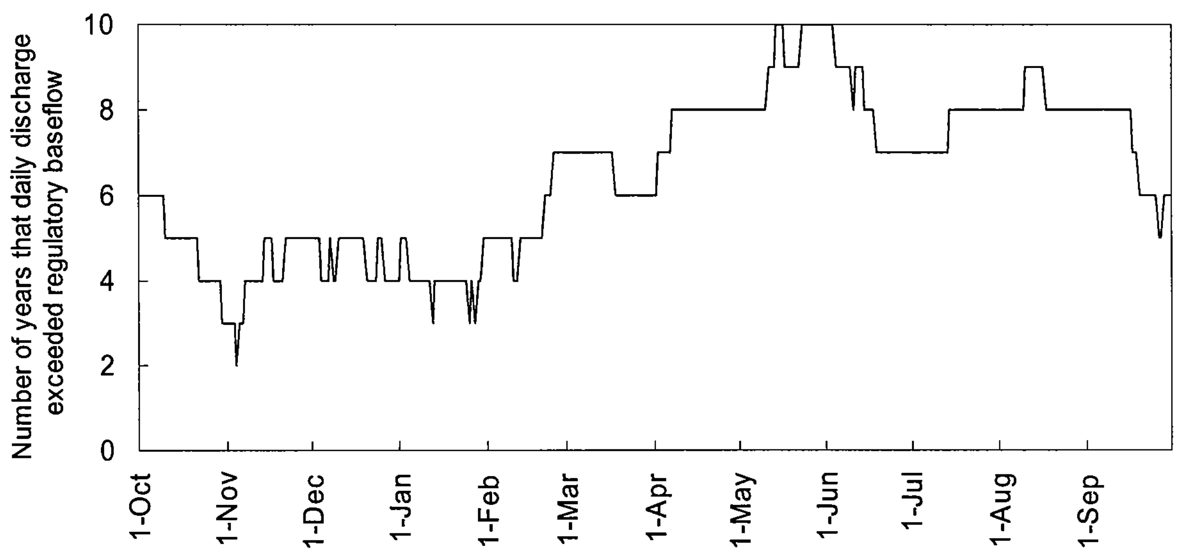


d. Twisp River near Twisp (USGS station 12448998)

Figures 2c and 2d. Frequency that daily discharge exceeded regulatory base flows at the Methow River at Winthrop and the Twisp River near Twisp for Water Years 1993 to 2002.



e. Methow River at Twisp (USGS station 12449500)



f. Methow River near Pateros (USGS station 12449950)

Figures 2e and 2f. Frequency that daily discharge exceeded regulatory base flows at the Methow River at Twisp and the Methow River near Pateros for Water Years 1993 to 2002.

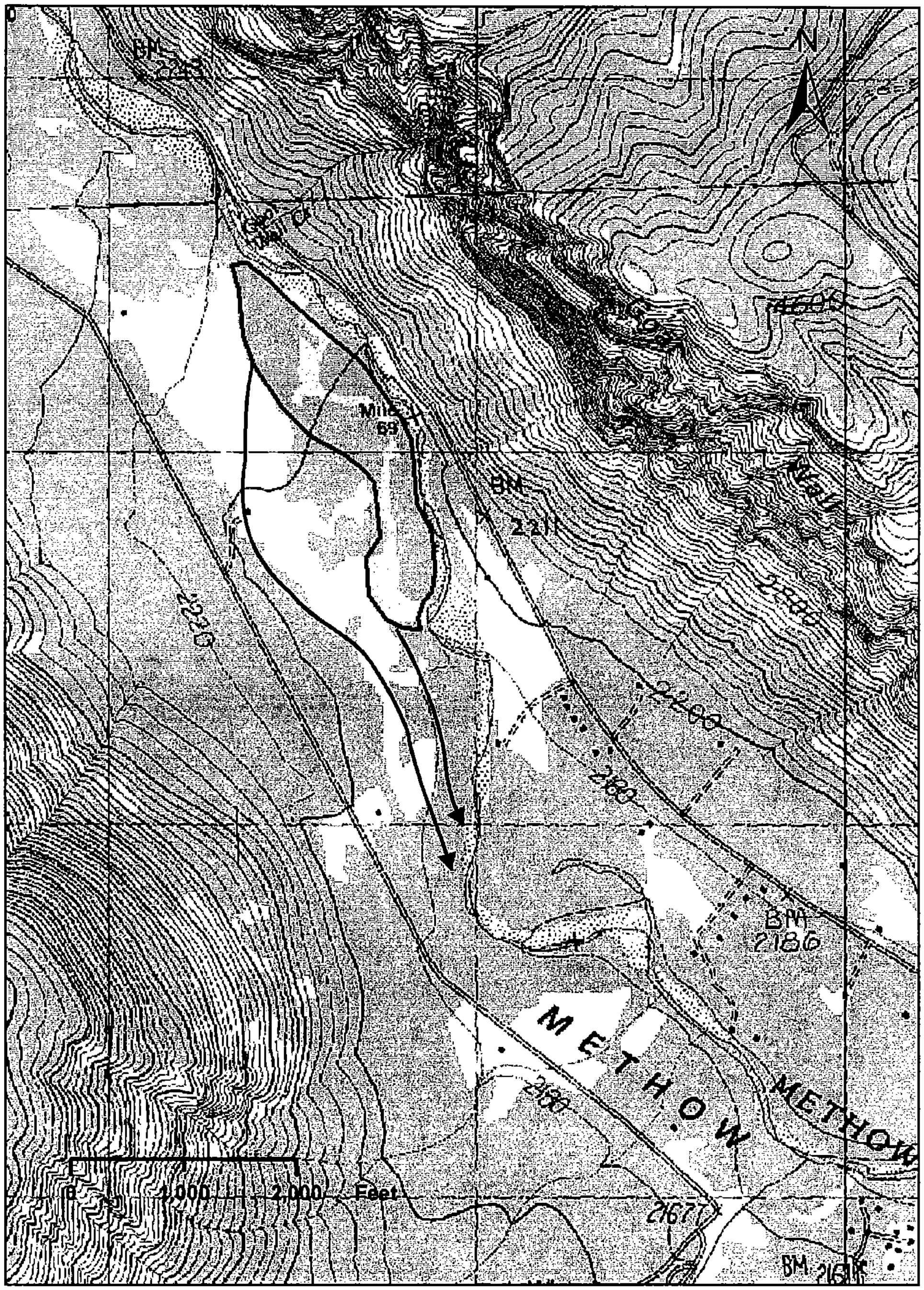


Figure 3. Methow River above Early Winters Creek with side-channel area (shaded), valley cross-section, and ground-water flow paths (lines with arrow ends).

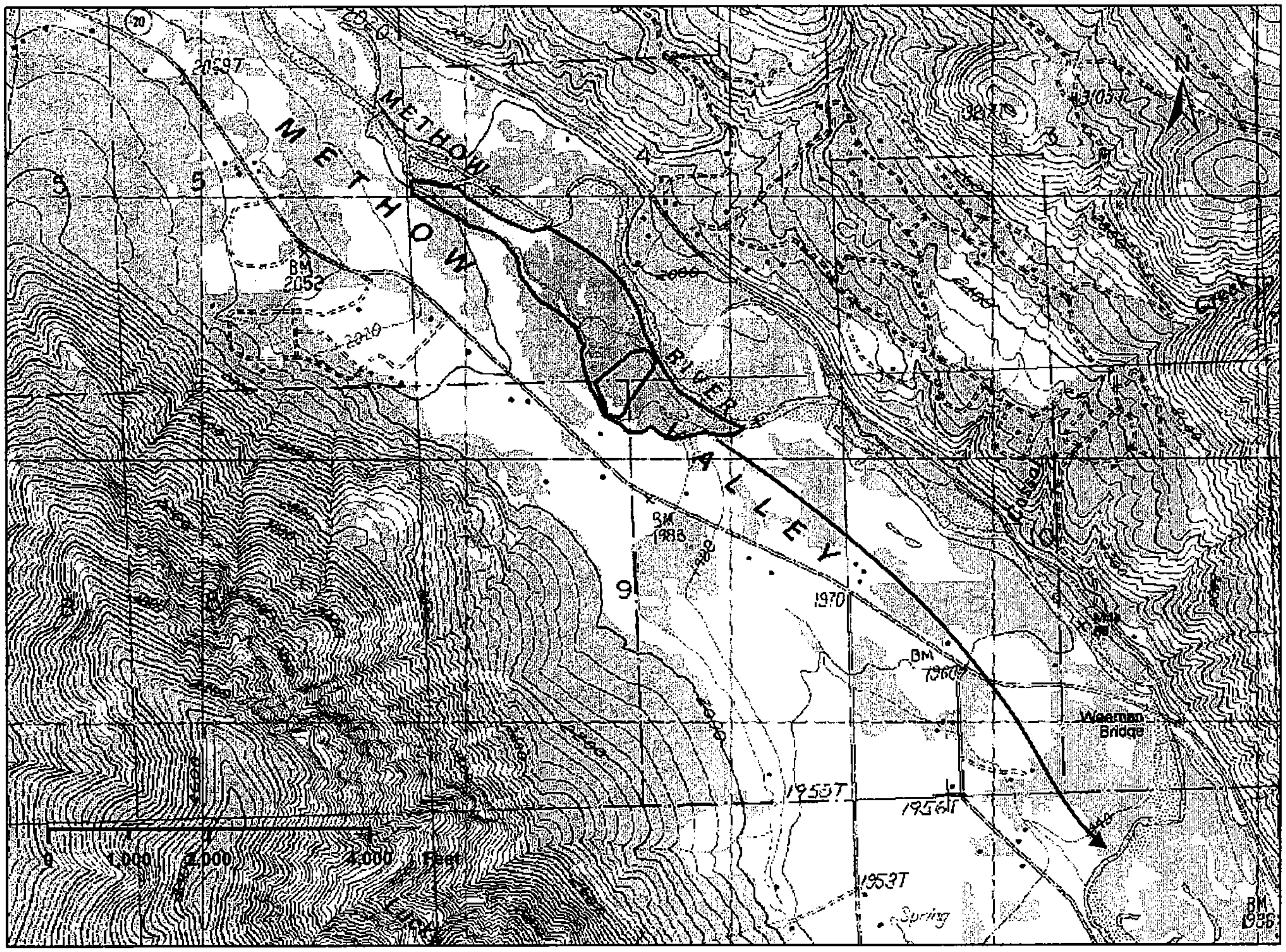


Figure 4. Methow River at Fawn Creek with side-channel area (shaded), valley cross-section (line), and ground-water flow paths (lines with arrow ends).

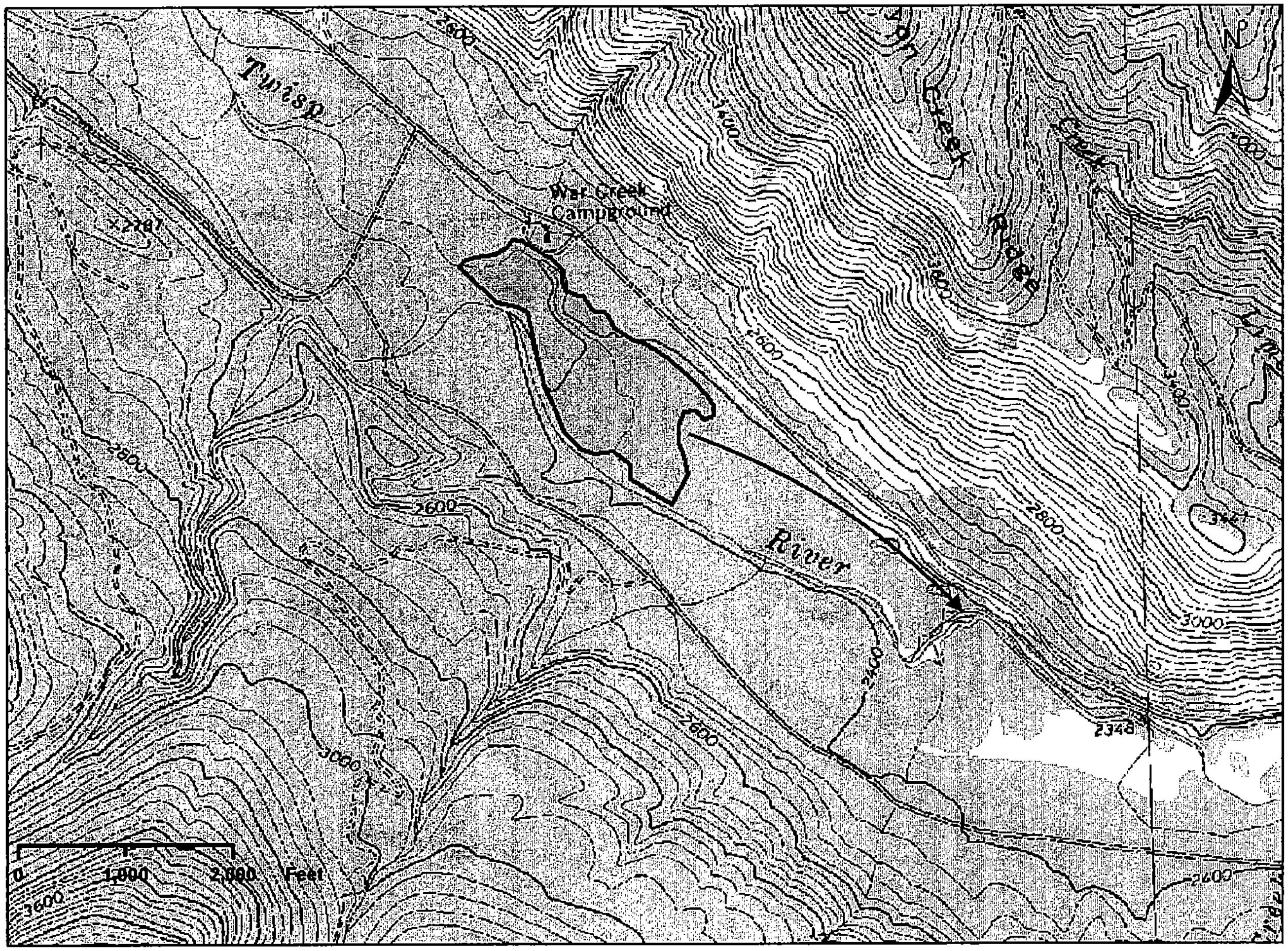


Figure 5. Twisp River at War Creek with side-channel area (shaded), valley cross-section (line), and ground-water flow paths (lines with arrow ends).

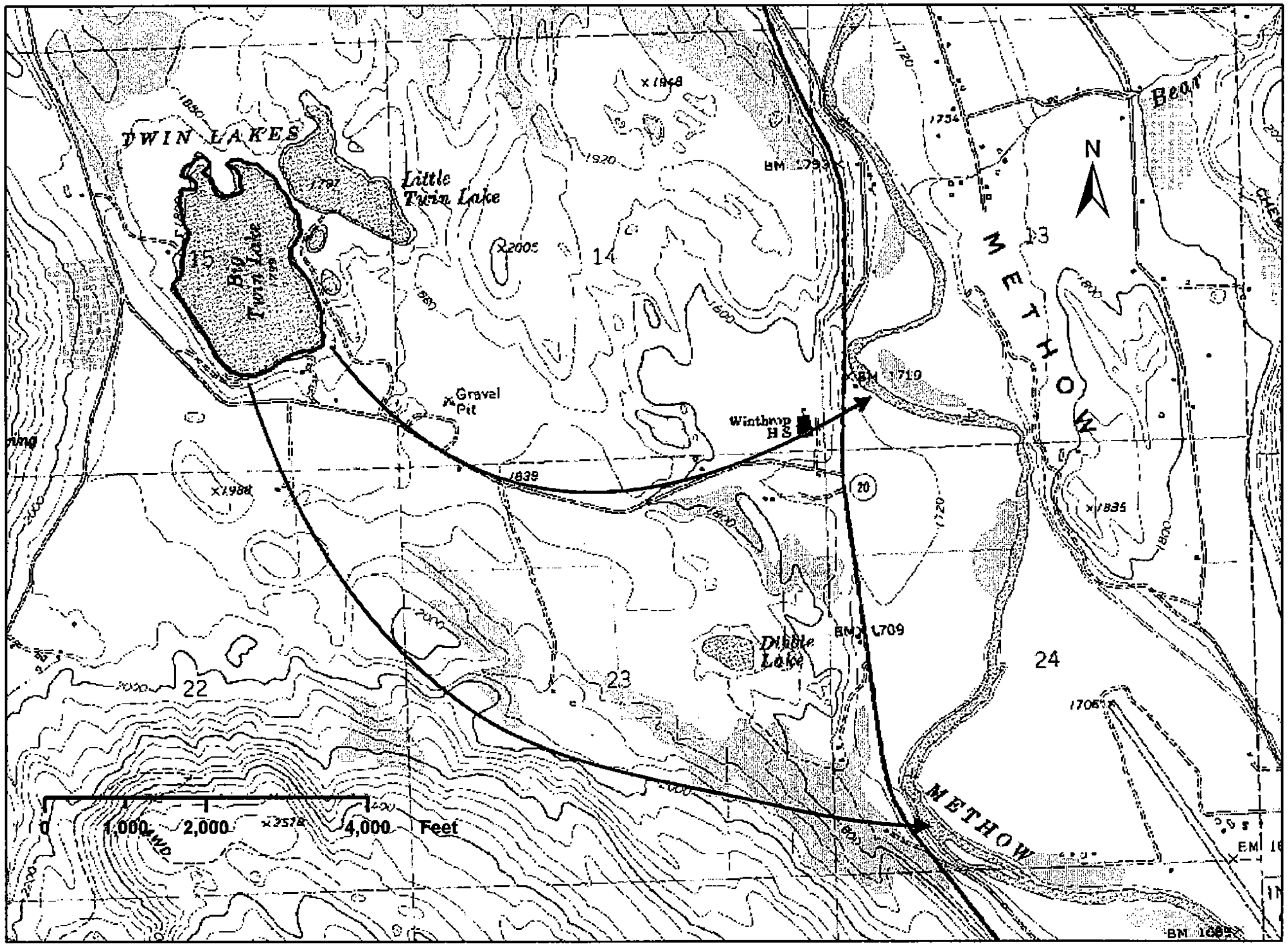


Figure 6. Big Twin Lake (shaded), valley cross-section (line), and ground-water flow paths (lines with arrow ends) .

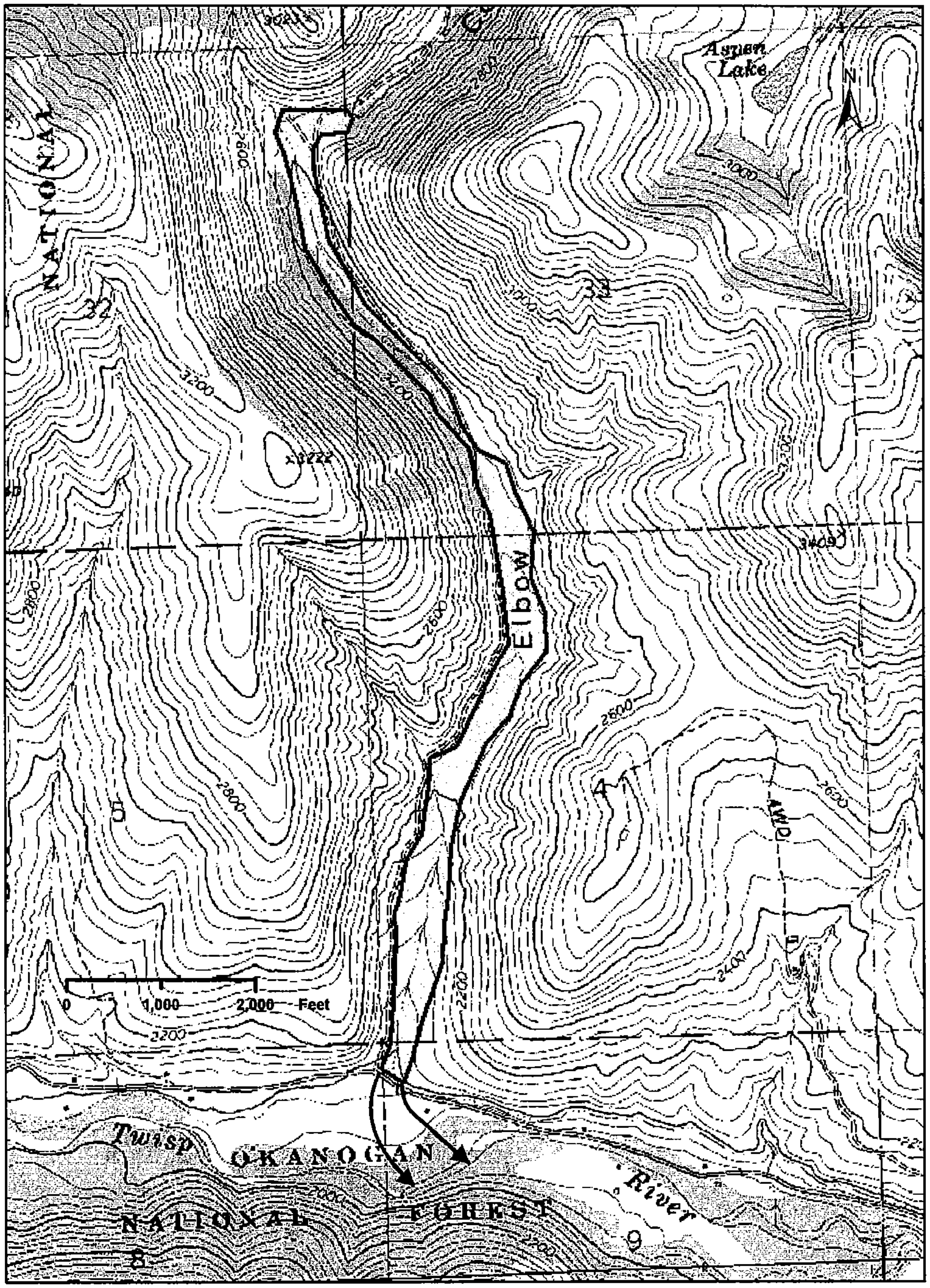


Figure 7. Elbow Coulee (shaded), valley cross-section (line), and ground-water flow paths (lines with arrow ends).

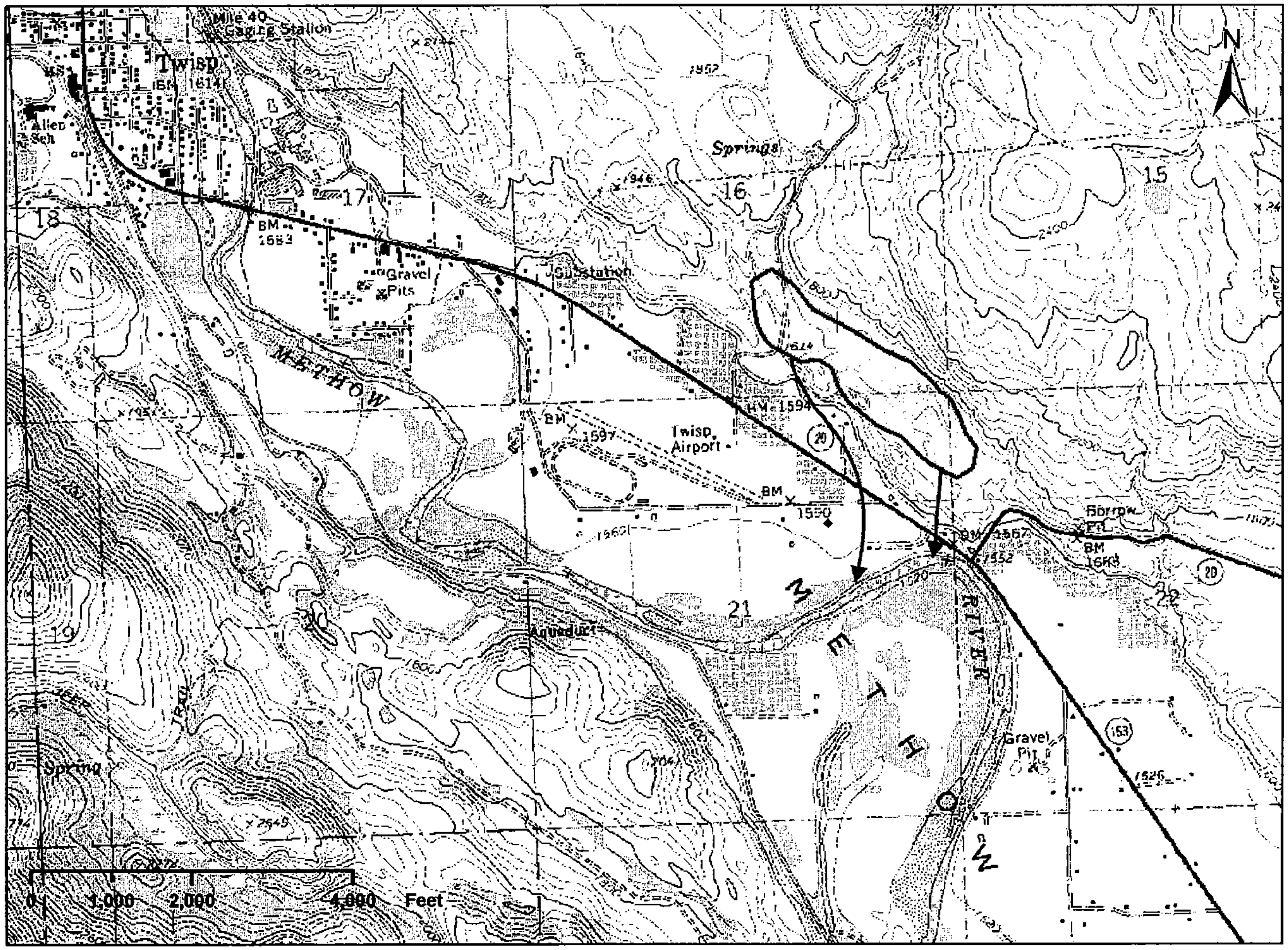


Figure 8. Terrace southeast of Twisp (shaded), valley cross-section (line), and ground-water flow paths (lines with arrow ends).

Figure 9. Side channel of the Methow River above Early Winters Creek with estimated depth to ground water. Digital orthophoto source: U.S. Forest Service, 1998a.

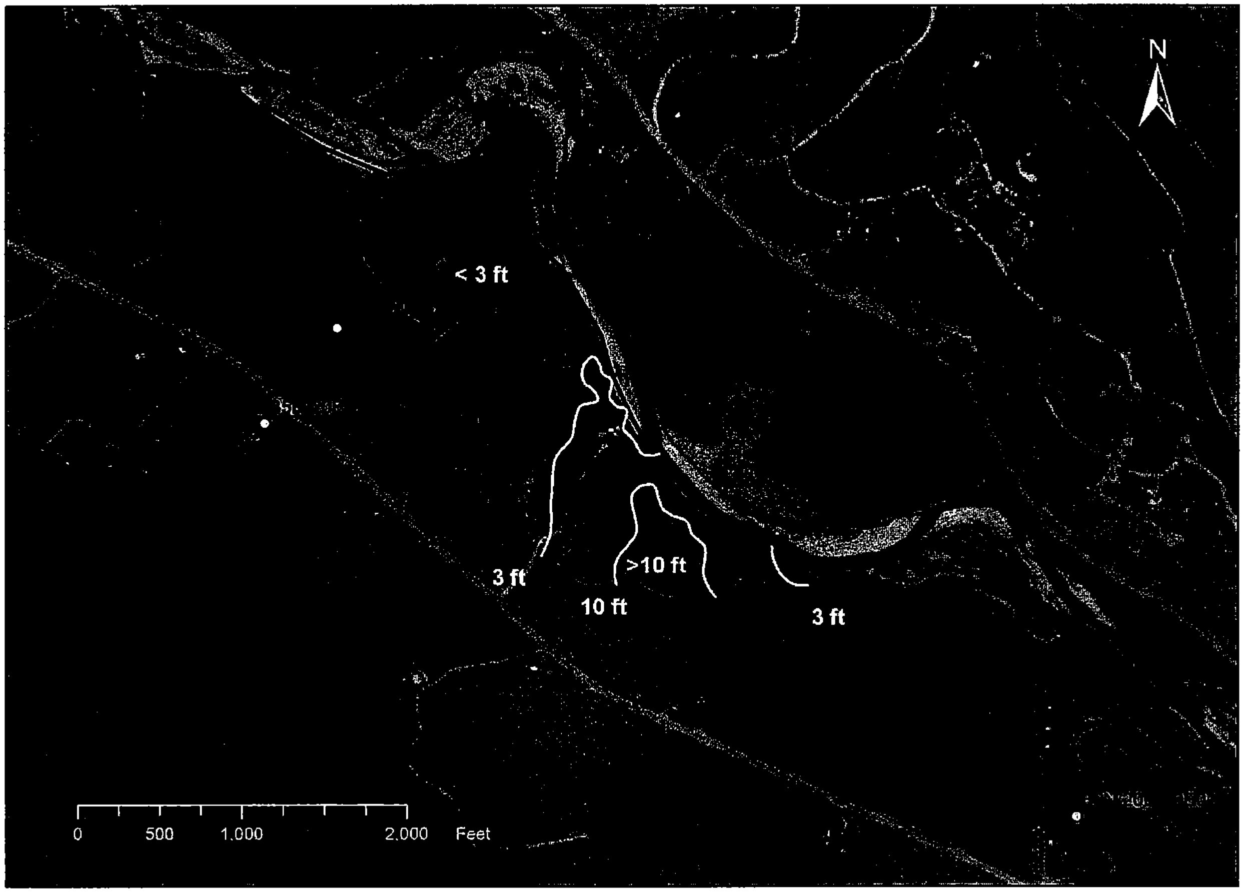


Figure 10. Side channel of the Methow River at Fawn Creek with estimated depth to ground-water. Digital orthophoto source: U.S. Forest Service, 1998b.

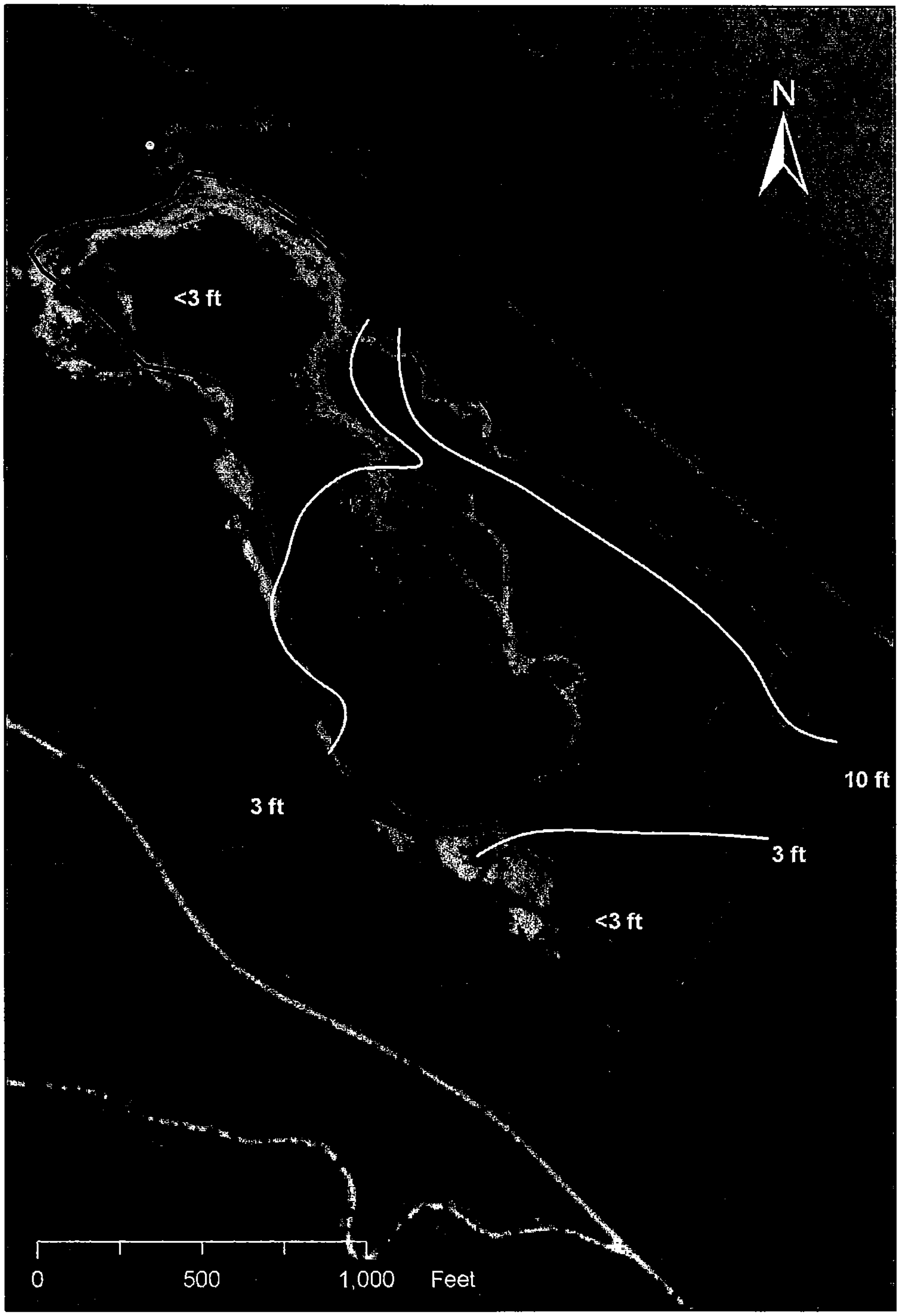


Figure 11. Side channel of the Twisp River at War Creek with estimated depth to ground water. Digital orthophoto source: U.S. Forest Service, 1998c.

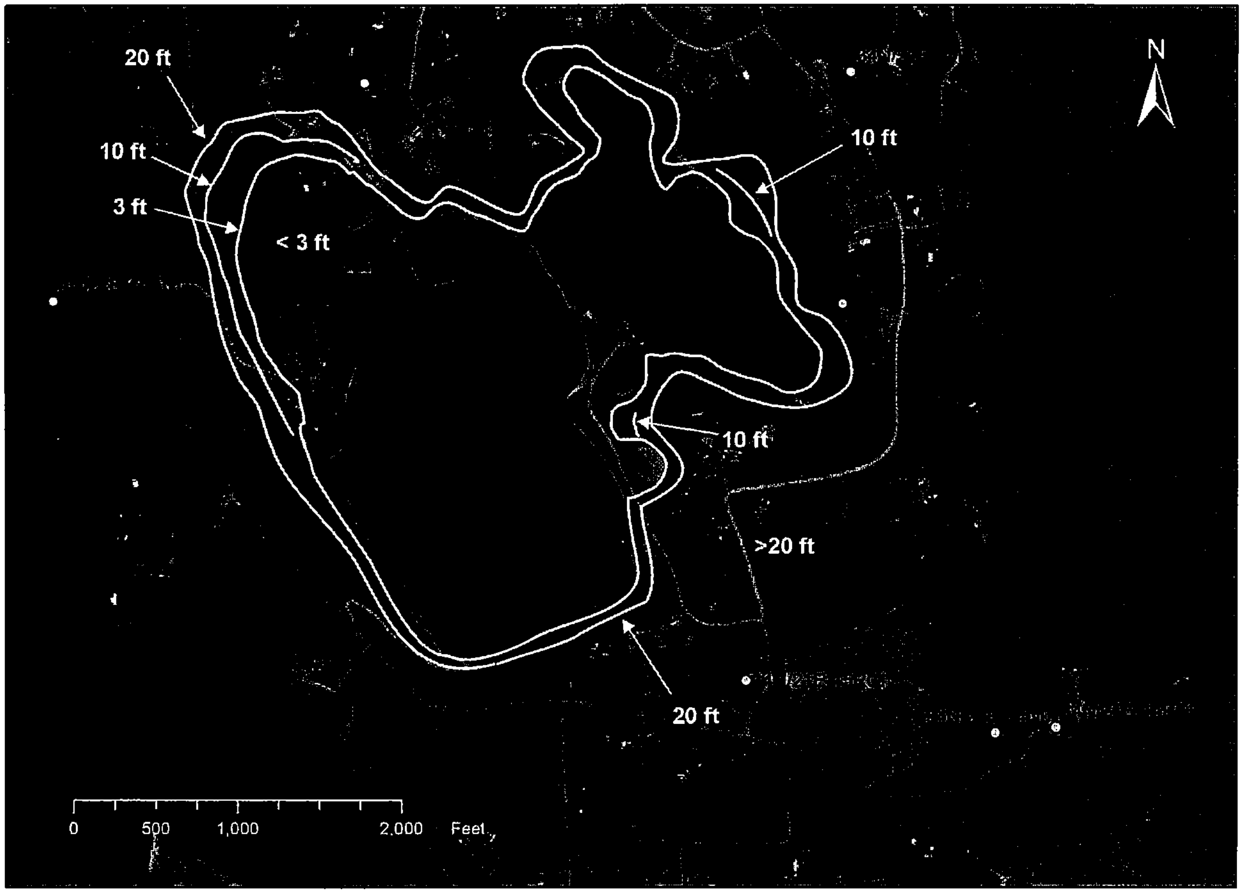


Figure 12. Big Twin Lake, Winthrop with estimated depth to ground water. Digital orthophoto source: U.S. Forest Service, 1998d.

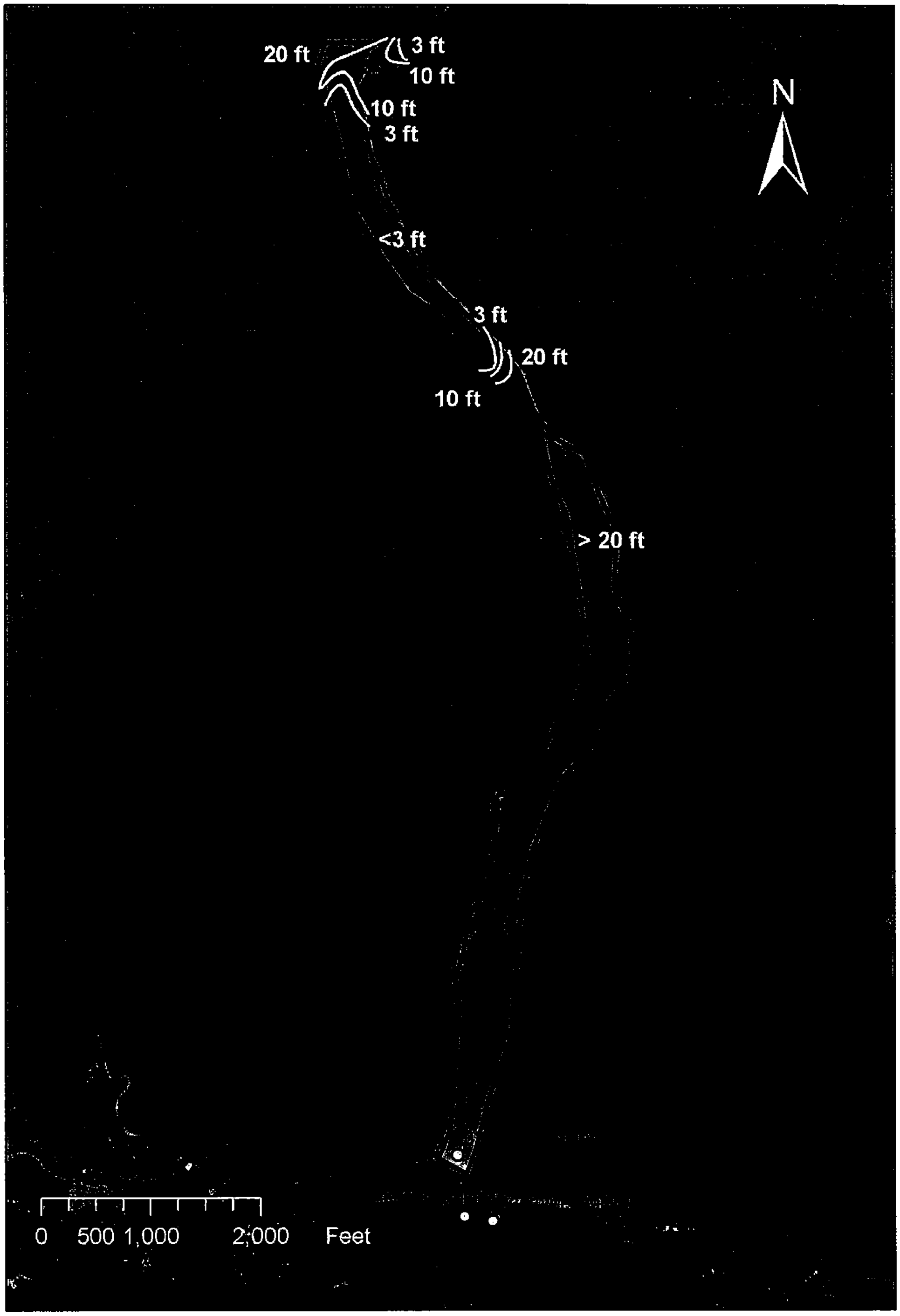


Figure 13. Elbow Coulee, Twisp River with estimated depth to ground water. Digital orthophoto source: U.S. Forest Service, 1998d.

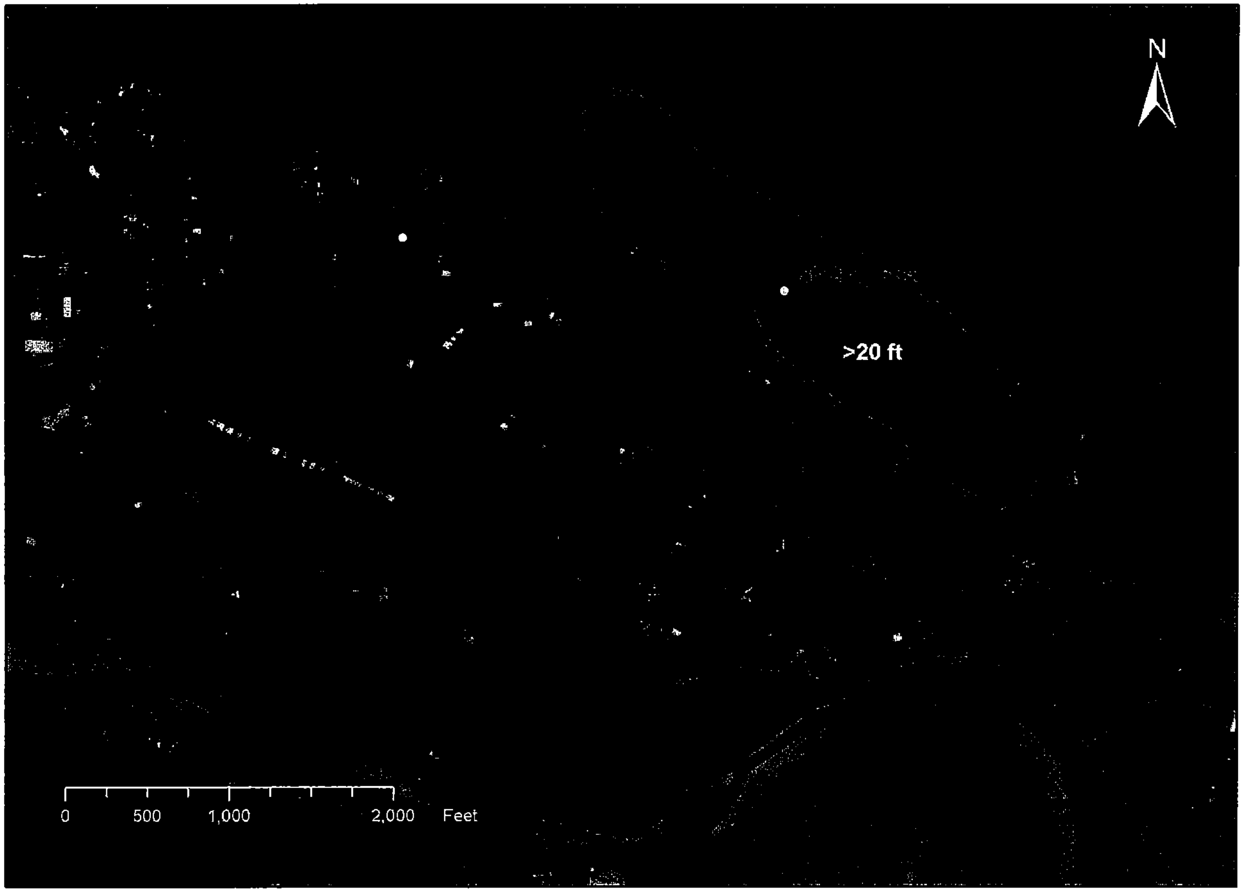


Figure 14. Terrace southeast of Twisp, Methow River above Beaver Creek with estimated depth to ground water. Digital orthophoto source: U.S. Forest Service, 1998e.